2008

Correlation between visual perception and waviness measurements for coated surfaces

Geethashree Hemashankar
University of Windsor

CORRELATION BETWEEN VISUAL PERCEPTION AND WAVINESS MEASUREMENTS FOR COATED SURFACES

by

Geethashree Hemashankar

A Thesis
Submitted to the Faculty of Graduate Studies
through Civil & Environmental Engineering
in Partial Fulfillment of the Requirements for
the Degree of Master of Applied Science at the
University of Windsor

Windsor, Ontario, Canada
2008

Your file Votre référence
ISBN: 978-0-494-57561-1
Our file Notre référence
ISBN: 978-0-494-57561-1

Author's declaration of originality

I hereby certify that I am the sole author of this thesis and that no part of this thesis has been published or submitted for publication.

I certify that, to the best of my knowledge, my thesis does not infringe upon anyone's copyright nor violate any proprietary rights and that any ideas, techniques, quotations, or any other material from the work of other people included in my thesis, published or otherwise, are fully acknowledged in accordance with the standard referencing practices. Furthermore, to the extent that I have included copyrighted material that surpasses the bounds of fair dealing within the meaning of the Canada Copyright Act, I certify that I have obtained a written permission from the copyright owner(s) to include such material(s) in my thesis and have included copies of such copyright clearances to my appendix.

I declare that this is a true copy of my thesis, including any final revisions, as approved by my thesis committee and the Graduate Studies office, and that this thesis has not been submitted for a higher degree to any other University or Institution.

Abstract:

This research study investigates the factors influencing the overall appearance of an automobile and intends to develop a scientifically-justified quality standard for automotive coatings based on the BYK instrument and human perceptions of quality. Painted panels of three different colors; silver, white and blue were visually evaluated by 30 panelists of various demographic backgrounds, who ranked the paint panels individually from the best to worst.

Ranking of silver and white paint panels exhibited strong correlations (R^2 adjusted = 82.0% and 90.3%) with BYK parameters. The measured BYK values of paint panels remain statistically unchanged before and after the experiment. Blue colored panel data resulted in a regression model with a weak correlation (23.4%) between median rank and the BYK parameters. Further studies need to be conducted to establish a scientific method to obtain an acceptable value for BYK parameters.

Dedication

This thesis is dedicated to the memory of my cherished Father, who exemplified personal integrity leaving an everlasting impression that I will continue to embrace throughout my life.

I look behind and after
And find that all is right,
In my deepest sorrows
There is a soul of light

- Swami Vivekananda

You don't develop courage by being happy in your relationship everyday.
You develop it by surviving difficult times and challenging adversity.

- Greek Philosopher

Acknowledgment

This work is the result of the dedication, effort and support of many individuals. I am particularly beholden to my advisor Dr. Paul Henshaw for his altruistic help, expert guidance, insightful comments and incessant zeal which all contributed immensely to the completion of this research study. He is truly one of those rare individual who is both an outstanding educator and a truly wonderful person. He has provided me with a solid foundation that I will continue to build for the rest of my career. I thank him for that.

I would like to express my profound gratitude to Dr. Sudhir Paul for readily accommodating my schedule, the abundance of help he provided in channeling the study in a positive direction and his guidance for my completion of my research study.

I would like to thank Dr. Edwin Tam and Dr. Rajesh Seth my external reader and chair for their willingness to serve on my committee as well as bringing their expertise to the table, which I believe has led to a strong document.

A special thank-you to Prof. Issac Barsky, for the time spent addressing numerous questions I encountered along the way.

The acknowledgment also goes to Mr. Bill Middleton for extending the help whenever required.

A multitude of thanks are extended to Tony Mancina, Chris Tighe, Marie Mills of DaimlerChrysler Automotive Research and Development Centre for contributing technical knowledge and sincere suggestions which were essential to this research study.

I owe a debt of gratitude to all participants of the study from the University of Windsor for their time and effort in completion of questionnaire and visual evaluation, without their cooperation this research truly would not have been possible.

I would like to extend thanks to Ms. Joann Grondin, Mrs. Catherine Wilson and Ms. Andria Turner for their assistance in various administrative matters.

Not to forget a heartfelt thanks to my "well – wishers", who have been a constant source of support for me through this all and provided many needed hugs during hard times.

Moreover I would like to thank my near and dear ones especially my Mom, my brother and my aunt for their positive reassurance and unwavering support. You are the best.

Finally I would like to thank my soul mate for his forbearance during the writing of this thesis.

Table of Contents

List of Tables

List of Figures

CHAPTER 1 - INTRODUCTION

1.1 Background

The automobile industry is a most dynamic industry with cutthroat competition among major players like GM, Chrysler, Ford, Toyota and Honda. Every year the market is flooded with new models and the customer has a huge choice of cars based on their design, performance, features etc. In the domain of consumer products, product acceptance is influenced by wider range of factors than cost alone.

One of the most influential factors in selecting a passenger car is its appearance. Appearance plays a vital role in the development, marketing and sales success of a wide range of automotive products. In many markets customers judge the quality of products unconsciously by their surface appearance. This is why original equipment manufactures (OEMs) take special care in this area while manufacturing their products.

A vehicle undergoes a number of processes before it leaves the assembly line. Of all these processes, the painting process is the most energy intensive and produces the greatest proportion of emissions of regulated chemicals like hazardous air pollutants (HAPs) and volatile organic compounds (VOCs). Automotive coating consists of a system of up to six layers of different coating materials. These six layers are applied separately, but work together to provide corrosion protection, durability, and color (Geffen et al., 2000). Perceptions of coating appearance vary with observer, with lighting condition, with viewing angle and with viewing time.

1.2 Problem justification

The coating process accounts for a major portion of the air pollution emitted by automotive assembly plants. According to Environment Canada, over 5 kilotonnes of VOCs are emitted each year from automotive refinishing operations in Canada (Environment Canada, 2008). In order to comply with environment regulations, different coating and paint formulations are being developed and used to reduce the unwanted emission of hazardous chemicals, but also to ensure the health and well being of those working in assembly plants and consumers.

Many instruments are used in automobile factories to measure coating appearance quality. Autospec was the most common instrument used. Autospec, developed by Perceptron, measured gloss, distinctiveness of image (DOI) and orange peel. An overall appearance (OA) value was calculated by combining the measured gloss, DOI and orange peel values (Autospec – Profile, 2006). In recent years, BYK – Gardner developed an instrument called the Wave-scan – DOI that measures the waviness of the surface in more detail than Autospec. In spite of the advantages of the BYK's Wave-scan instrument, a proper relation between human perception and this measuring system is yet to be established in order to quantify a "good" paint finish / appearance.

1.3 Objective

This research study intends to develop a scientifically–justified quality standard for automotive coatings based on the BYK instrument and human perceptions of quality.

1.4 Scope

The scope of this research is:

- To collect data by having a study group conduct visual evaluation of different paint panels.
- To determine the most influential Wave-scan parameters affecting the overall appearance of coated surfaces.
- To establish a relationship between the optically measured appearance value and human perceived appearance quality.

CHAPTER 2 - LITERATURE REVIEW

Appearance is influenced by waviness and brilliance. If the human eye focus is only on the surface, the waviness characteristic is more prominent. On the other hand, if the focus of a human eye is on the image reflected from the painted surface, then we acquire information about the brilliance. Figures 1a and 1b illustrate the waviness and brilliance characteristics of a painted surface. The steel metal vehicle body is coated with several layers with sufficient curing and cooling between coats. The paint formulation consists of pigments and flakes bonded by an organic resin. When the paint is sprayed on a vehicle, spray droplets merge together, but incomplete levelling creates an undulation (Hill, 2004). The resulting paint surface would have a degree of undulation characterized by the size, shape and depth of surface structures. In addition, light is reflected in different directions depending on the undulation present on the illuminated paint surface.

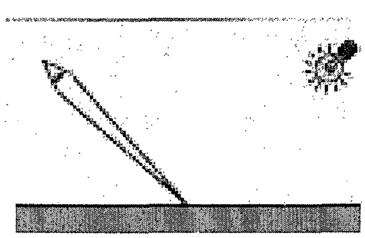


Figure 1a: Focus on surface

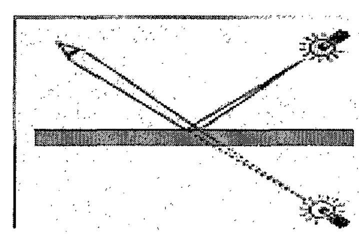


Figure 1b: Focus on reflected image

Reprinted with permission from Sherry Brown, BYK Gardner GmbH (Geretsried Germany) and BYK-Gardner USA (Columbia, USA)

The human optical system is sensitive to light in the visible range of the electromagnetic spectrum. A surface reflecting light in the viewing direction of an observer's eye is perceived as a light area. Thus, we perceive the pattern of light and dark areas as waviness. This is depicted in Figure 2.

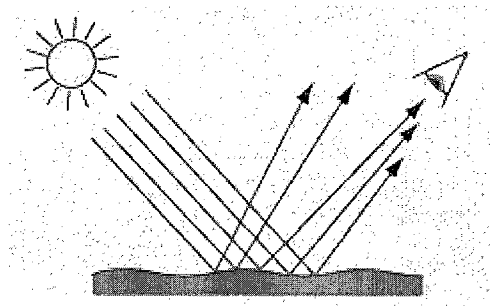


Figure 2: Reflection of light from a wavy surface. Reprinted with permission from Sherry Brown, BYK Gardner GmbH (Geretsried, Germany) and BYK-Gardner USA (Columbia, USA)

The waviness of a painted surface is measured in terms of variation of undulations in structure size using the Wave-scan DOI developed by the German company BYK-Gardner, to simulate the visual impression obtained from optical inspection of surface structures. Here, the measuring principle is based on the reflection of the light of a small laser diode by the surface structures of the sample. The laser light shines on the surface at an angle of 60°, and the reflected light is detected at the secular gloss angle (60° opposite). During the measurement, the instrument is rolled across the sample surface over a length of approximately 10 cm, with a data point being recorded every 0.027 mm. Figure 3 shows an optical profile (detector signal) during a scan. Flat portions of the surface (top of the hill and bottom of the valley) reflect the laser light into the detector, resulting in a high signal in optical profile.

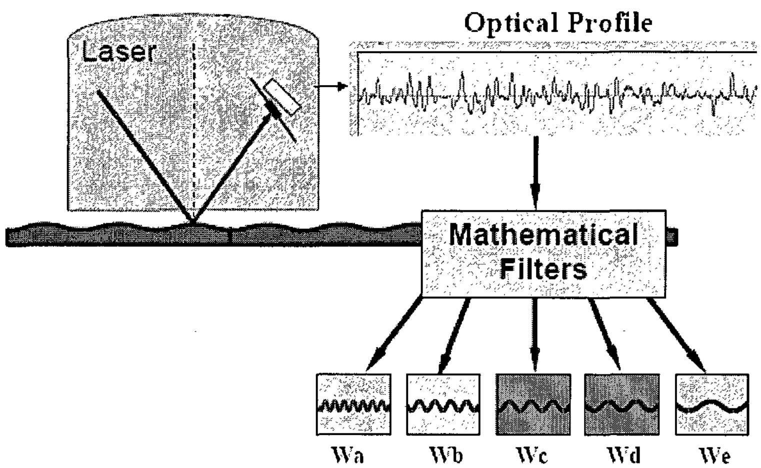


Figure 3: Working principle of Wave-scan DOI. Reprinted with permission from Sherry Brown, BYK Gardner GmbH (Geretsried, Germany) and BYK-Gardner USA (Columbia, USA)

The optical profile is broken into several bands termed "*structure sizes*" or Wave-scan "*elements*", with wavelengths of 0.1 to 30 mm, as computed by mathematical filtering (BYK Gardner, 2006). A contrast value is obtained by standardizing each of the light intensity profiles. Each of these Wave-scan elements has a "contrast value", ranging from 0 to 100, which is related to the average amplitude of the waves. The surface waviness will decrease with lower values of contrast. Additionally, an LED light source is installed in the Wave-scan DOI and illuminates the surface at an incident angle of 20° after passing an aperture. The scattered light is detected and a "*dullness*" value (du, <0.1 mm) is measured. Table 1 summarizes the five undulation wavelength ranges.

Table 1: Wavelength ranges measured by Wave-scan DOI

Wave–scan element	wavelength range (mm)
Dullness	<0.1
Wa	0.1 – 0.3
Wb	0.3 – 1.0
Wc	1.0 – 3.0
Wd	3.0 – 10.0
We	10 – 30.0

The appearance is evaluated by Autospec in terms of DOI, orange peel and gloss. Orange peel is a surface condition characterized by irregular waviness of the system resembling an orange peel. Orange peel is a description for surface structures, which we see as a wavy pattern of bright and dark areas. Chrysler uses a customized set of panels with evenly varied degrees of orange peel. These panels were prepared at ACT laboratories and rated by an "R" value from one to ten (1 being the roughest) and used as standard panels. Orange peel is evaluated by visual comparison to the ACT panels. A Tension Meter, a PGD meter, a Visio paint meter, an Autospect QMS – BP or the Wave- scan instrument can also be used. Orange peel is depicted in Figure 4.

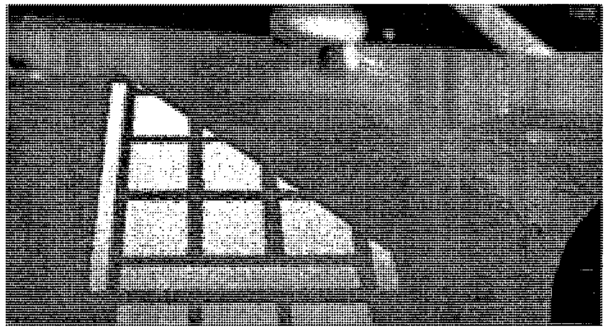


Figure 4: Orange peel on a car surface, Reprinted with permission from Sherry Brown, BYK Gardner GmbH (Geretsried, Germany) and BYK-Gardner USA (Columbia, USA)

The visibility of these structures is dependent on their size and also on the observing distance to the surface. The greater the distance, the smaller a structure will appear. Figure 5 shows that the detectable structure size depends on the observing distance. Smaller structures are visible at a closer distances and vice-versa (Fensterseifer, 2004). Figure 5 shows that the optimum distance for visibility of structures from 10 to 30 mm wavelength is a distance of about 3 m. However, Fensterseifer (2004) states that the short waves in the range of 0.1 to 1 mm, are better recognized at a close distance. Fine structures that are below the human eye's resolution (under 0.1 mm) can no longer be recognized as a light/dark pattern. Such structures reduce the sharpness and contrast of a reflected image, i.e. the distinctness of image (DOI). Additionally, the reflection properties affect the perception of orange peel; higher brilliance makes the long waves more distinctly visible. Therefore, the perceived surface appearance is a result of the interrelation between small and large structures.

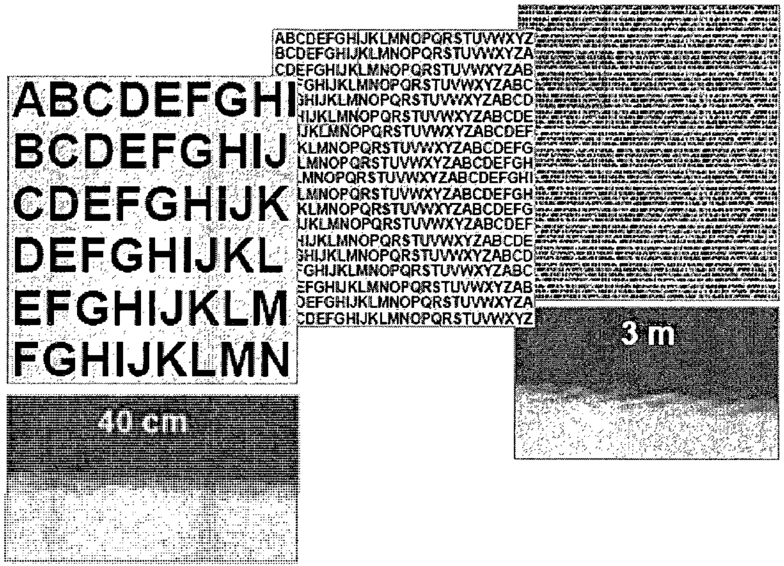
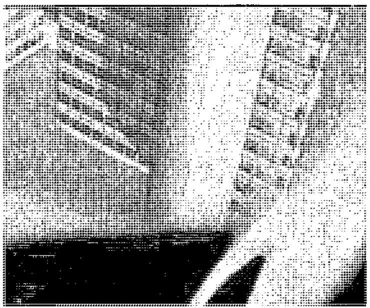


Figure 5: Association between observing distance and resolution of human eye. Reprinted with permission from Sherry Brown, BYK Gardner GmbH (Geretsried Germany) and BYK-Gardner USA (Columbia, USA)

DOI is the reflective characteristic of a coating, where the sharpness of the image of an object reflected on the paint surface is assessed. Figure 6a illustrates a sharp/distinct image reflected by a paint surface. When distinctness of image (DOI) is diminished, the surface looks less brilliant/diffused as depicted in Figure 6b. A Landolt ring, an Autospec, or a Wave-scan DOI are used as visual tools to assess DOI (Böckler, 2004). If needed, DOI can be calculated by combining the short wavelength Wave-scan elements: Du, Wa, and Wb.



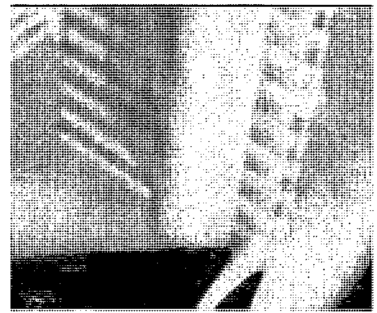
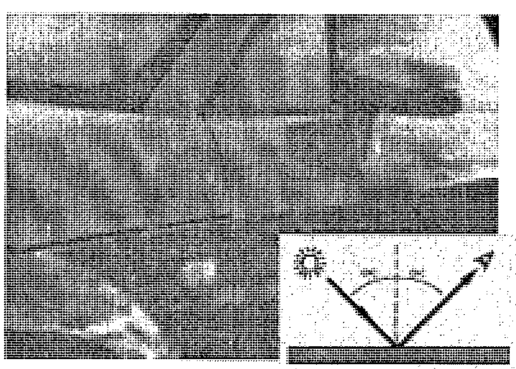


Figure 6a: Sharp/Distinct image. **Figure 6b: Diffused image.**

Reprinted with permission from Sherry Brown, BYK Gardner GmbH (Geretsried, Germany) and BYK-Gardner USA (Columbia, USA)

Gloss is defined as 'the angular sensitivity of reflectance, involving surface related light, responsible for the degree to which reflected highlights or images of the objects may be seen as superimposed in a surface' (ASTM standard E284). Gloss is due to specular reflection, where the detector is placed at an angle of reflection equal to the angle of incidence of the light source. Similar to colour, Gloss is a multidimensional optical phenomenon. Figures 7a and 7b depict a high gloss and semi – gloss surface respectively.



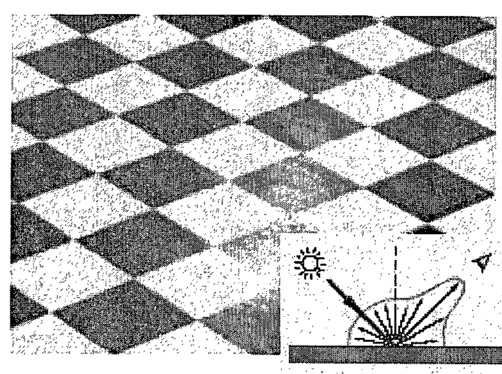


Figure 7a: Reflection from a high gloss surface **Figure 7b: Reflection from a semi to matt gloss surface**

Reprinted with permission from Sherry Brown, BYK Gardner GmbH (Geretsried Germany) and BYK-Gardner USA (Columbia, USA)

In addition to the Wave-scan structure sizes (Du, Wa, Wb, Wc, Wd, We) there are two more characteristics of appearance that can be measured with the Wave-scan DOI: *wet look (WL) and longwave coverage (LC).* These values are calculated using Equations 1 and 2, respectively.

$$WL = \frac{Wd - Wc}{Wd + Wc} \tag{1}$$

$$LC = \frac{Wb - Wd}{Wb + Wd} \tag{2}$$

When short wave structures are predominant, they conceal the long waves present on the coated surface. This is the basis for LC. In addition, the surface has a distinct wet look when the Wd/Wc ratio is high. A low value of WL, results in an optical impression referred to as fibrous (Lex, 2005). A high value of WL results in a surface that looks wet and smooth.

The uniform color space CIE $L^*a^*b^*$, of the Commission Internationale de l'Eclairage, was internationally adopted in the 1970's for the purpose of color acceptability decision making from color measurements by spectrophotometers and colorimeters. It is a three dimensional space, consisting of two axes, a* and b* at right angles to each other, which represent the hue dimension of color. The third axis L*, which indicates the lightness or luminance of color, runs perpendicular to the a*b* plane. The color space is illustrated in Figure 8.

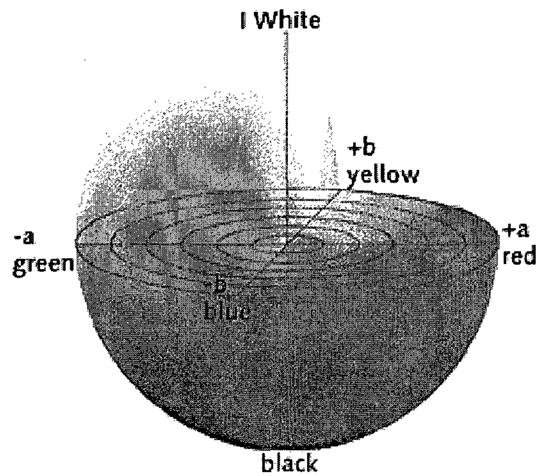


Figure 8: The CIE L*a*b* color space (Lex, 2004)

Lex (2004) proposed a '*structure space*' as an alternative measurement system for appearance, which is analogous to the L*a*b* color measurement (Figure 9). The structure space is designed on a Wb-Wc-Wd ratio (Lex, 2004). The horizontal axes represent WL and LC and the vertical axis give us an idea about the degree of smoothness of a painted surface.

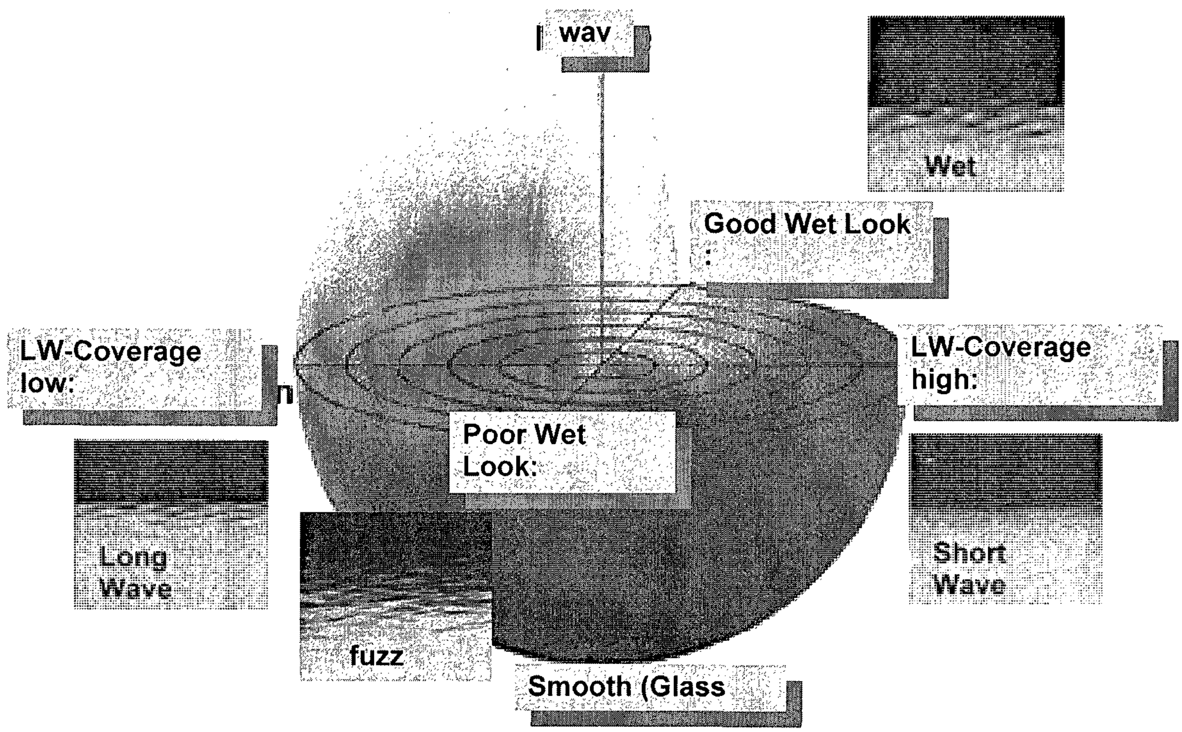


Figure 9: The BYK structure space (Lex, 2004)

Böckler (2004) investigated differences in appearance between upper and medium class automobiles. In this benchmark study, new Mercedes car bodies of seven different models of medium class and five different models of upper class were selected. Car bodies with silver and dark metallic colors were analyzed. The horizontal surfaces such as the hood, and vertical surfaces, such as doors, of the car were the main check zones. Analysis of the longwave (LW), the shortwave (SW) and DOI for horizontal and vertical surface of dark metallic colored cars reveal that the ratio of the SW/LW is higher for upper class models when compared to medium class car models. On the other hand, the silver painted medium class vehicles showed relatively the same DOI value. This could be attributed to the metallic flakes present in the silver paint. Vertical surfaces (door) had higher longwave coverage values when compared to horizontal surfaces (hood) in almost all the car bodies considered for the study group. The results of the longwave, shortwave and DOI values were used in the formulation of a structure spectrum. The structure spectrum was then plotted in the structure space and it was found that the combination of high longwave coverage and high wet look values resulted in a wavy appearance on the painted surface, while a combination of high longwave coverage and low wet look would yielded a fuzzy to smooth appearance depending on the degree of Wd/Wc ratio (0 to -50). Studies to optimize the uniformity of structure space to visual perception are being carried out.

Gradischnig (2004) studied the correlation between the Wave-scan DOI and visual perception of structures for automotive finishes. Eleven black colored horizontal samples (hood, roof and trunk) and six black colored vertical surface samples of vehicles from four different assembly plants were selected. These coated surface samples were evaluated by twenty panelists, which included experts and non-experts in the field of paints and coatings. Visual evaluation was conducted in a special illuminated room that was equipped with a moveable sample holder. The visual evaluation was conducted from an observing distance of 1 – 3 m. A high correlation co–efficient value of 0.90 to 0.98 was obtained for horizontal and vertical surfaces respectively. An equation resulting in a 'rank – number' was developed by optimizing the regressed equation by the "determination measure" technique. The resulting equation was also independent of color and refractive index. Based on their findings of the structure spectrum, Gradischnig suggests that the presence of peaks at Wb (>25) and Wd (>13) in the structure spectrum would result in poor appearance of paint panel.

Giroux (2003) examined three different appearance – measuring methods to investigate the correlation between human evaluation and instrument readings. In this study, eleven measured parameters: Du, Wa, Wb, Wc, Wd, We, gloss, DOI, orange peel, longwave and shortwave were considered. The study was conducted by evaluating twenty-five black paint panels; panels were selected based on having a high or low value of each measurable parameter. These paint panels were evaluated by forty- five participants. Correlation analysis between visual evaluation and values measured by Autospect and Wave-scan DOI concluded that a combination of Wave-scan values correlated well to human perceived appearance value, since an R^2 (co-efficient of determination) value of 96% to 84% was obtained. The paint panels were also evaluated in terms of rank and magnitude by comparing to standard ACT "R" paint panels. In addition, the study also revealed that the participants without eyeglasses generally assigned lower R-values to the panels than their counterparts. Among the three appearance measuring systems – Perceptron's Autospect, BYK Gardner's Wave-scan plus and BYK-Gardner's Wave-scan DOI – BYK-Gardner's Wave-scan DOI produced the highest rate of correlation with human evaluation of paint appearance.

Based on a study of the correlation of instrumental and sensory data, Morland and Mikec (2004) made an effort to develop a measurable characteristic of appearance. Their study concludes that a sensory metrology can allow the study of aptness of the measuring instruments and organizing different types of paint appearance. Eighty paint panels consisting of 16 different colors (eight solid and eight metallic) were used in the evaluation study. Ten experts and a hundred and twenty consumers participated in the evaluation study. The panels were evaluated in different viewing conditions. The study found a correlation between measured attributes (orange peel, DOI and "shine"), the opinions of expert subjects and certain Wave-scan parameters namely (Du, Wa, Wb, and Wd). However, no conclusion could be established with regard to specifying an universal criteria of appearance and predicting the level of quality perceived by customers.

CHAPTER 3 - MATERIALS AND METHODS

3.1 Materials

3.1.1 Paint panels: The paint panels were prepared at the University of Windsor/ Chrysler Automotive Research and Development Centre (ARDC) in Windsor, Ontario, Canada. The ARDC is equipped with a fully automated coating facility. Initially paint of three different colors, namely Bright Silver Metallic (WS2), Stone White (SW1) and Marathon Blue Pearl (EBD) were selected based on the different paint families (Morland and Mikec, 2004) as well as on their popularity and market trend (ARDC, DuPont, 2006). A set of roughly 300 paint panels for each color with different appearances were prepared at ARDC as a part of a process DOE study.

3.1.2 D-65 illuminants: A total of forty-eight; D-65 daylight fluorescent tubes were used for the visual evaluation of paint panels. They were purchased from General Electric Lighting, and installed in room 107 E Essex Hall, University of Windsor.

3.1.3 Wave-scan DOI: The undulation/ wavelengths on the paint panels were measured with a Wave-scan DOI, manufactured by BYK – Gardner, Geretsried Germany. The structure sizes measured were Du, Wa, Wb, Wc,Wd and We.

3.1.4 MA-68 Multi-angled spectrophotometer: The precise color present on the metallic paint panels was measured and spectral data was collected at five different angles 15°, 25°, 45°, 75° and 110°. This instrument is developed by X-Rite America, Grand Rapids, Michigan, USA.

3.1.5 Lightmeter: The light intensity of room 107 E Essex Hall was measured using a light meter K7020 manufactured by Kleton, purchased from ITM Instruments Inc., Canada.

3.1.6 Minitab: The response data were analyzed with the help of Minitab 15, statistical software (Minitab Inc., State College, Pennsylvania, USA).

3.2 Experimental setup

A standard method to evaluate overall visual appearance based on surface roughness is not established. This visual evaluation was conducted in rough accordance with *ASTM standard D1729; Visual appraisal of colors and color differences of diffusely – illuminated opaque materials*, since the combination of chromatic characteristics (color) and geometry (gloss, texture, shape, "shininess", haze) influence the overall appearance. The room was equipped with D65 illuminants to ensure an ambient lighting condition similar to daylight. According to the *illuminating engineering society* of North America (IES), a range of 1000 – 1500 lux should be maintained during an inspection activity (ANSI IES RP-7, 1983). The light meter (Section 3.1.4) was used to measure the light intensity. A light intensity of 1020 to 1300 lux was maintained throughout the visual evaluation.

The paint panels were laid against a dark, matte finish background cloth so that the paint panels appear distinct enough to be judged by the participants (ASTM D1729-96, 2003). The table holding the panels was positioned so that the paint panels were illuminated from directly above and were viewed from a 45-degree angle by leaving the panels against a bar held by adjustable laboratory clamps, which was under the black cloth. The paint panels were evaluated at an observing distance of 0.5 to 2 m by positioning the panels at the far edge of a 0.6 m table.

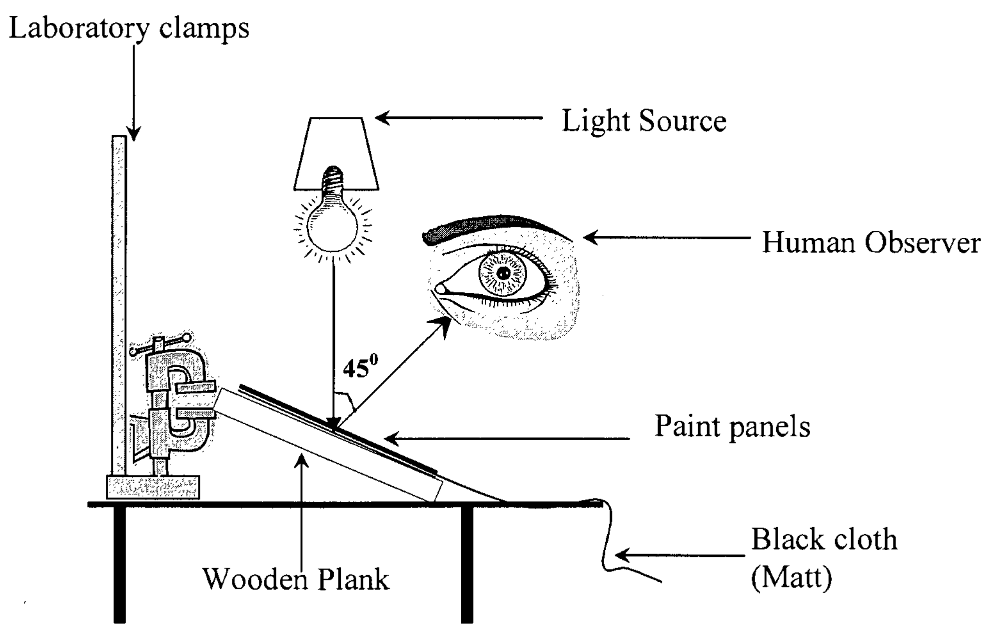


Figure 10: Side-view of experimental setup for evaluating panels.

3.3 Experimental procedure

3.3.1 Panel selection

The averages of all six predictor variables (Du, Wa, Wb, Wc, Wd and We) for each color of a given DOE set were identified. Paint panels for each color were then selected such that a panel had a value for a particular variable that was well above or below the mean, while the values for the other variables were within five contrast points of the mean. A set of 16 paint panels for the silver color were selected. From the initial silver evaluation, by observing the panelists and considering their opinion, it was determined that there were too many paint panels resulting in difficulty in judging the paint panels. Hence it was decided to select 14 paint panels for white and blue colors. Of the 14 panels selected for white, it was found that two paint panels had coincident deviation in both Wc and Wd, and there were another two paint panels which had slightly a different shade of white. These were excluded so that only 10 white paint panels were selected. The summary of wave – scan characteristics of selected paint panels is in Appendix A.

The paint panels were scanned before and after the evaluation using the BYK Gardner Wave-scan DOI to verify if there was any significant change in the measured values during handling of the panels. The range of different parameters for each color was also identified from a previous in-plant study (Ruvinova, 2006). Table 2 summarizes the characteristics of these panels. The details of different parameter range considered while selecting a paint panels for each color is tabulated in Appendix J.

Table 2: Wave-scan characteristics of silver, white and blue painted panels and vehicles

		DOE panels		In plant values (Ruvinova,2006)		Present study	
		Range	Average	Range	Average	Range	Average
Silver	Du	17.5-31.6	22.2	19.0-56.0	37.50	18.2-24.7	22.2
	Wa	10.4-33.6	18.1	3.0-27.0	15.00	12.4-22.3	17.4
	Wb	21.7-47.4	32.8	11.0-45.0	28.00	23.8-38.7	32.9
	Wc	12.6-45.6	21.2	9.0-42.0	25.50	14.3-25.9	20.3
	Wd	13.2-37.5	20.8	10.0-34.0	22.00	14.9-29.1	20.0
	We	5.9-21.2	10.4	4.0-19.0	11.50	9.0-14.4	11.0
	n		266		1261.0		16.0
White	Du	5.1-52.7	11.9	3.0-45.0	24.00	8.2-33.1	11.9
	Wa	5.5-47.9	18.3	4.0-42.0	23.00	6.1-47.9	18.5
	Wb	18.2-63.1	39.6	10.0-66.0	38.00	18.2-60.6	42.2
	Wc	14.3- 41.8	26.5	7.0-50.0	28.50	14.3-36.9	28.5
	Wd	18.4-34.9	24.6	14.0-46.0	30.00	20.7-30.5	25.8
	We	7.2-19.7	11.6	4.0-29.0	16.50	8.6-14.8	12.7
	n		280		1233.0		10.0
Blue	Du	5.8-28.9	11.8	14.1-61.7	37.90	8.4-21.4	12.0
	Wa	12 – 47.6	23.4	5.4-39.5	22.45	14.4-37.4	23.9
	Wb	28.9-63.6	44.9	3.9-59.2	31.55	30.9-56.7	45.9
	Wc	21.3-42.2	27.6	8.3-49.6	28.95	23.9-42.2	29.9
	Wd	19.6-36.8	25.6	11.4-41.7	26.55	19.6-36.6	26.9
	We	8 – 17.7	12.9	4.4-26.9	15.65	9.6-17.7	13.5
	n		138		1232.0		12.0

3.3.2 Panelist selection

An invitation regarding the visual evaluation was sent to students, faculty and staff of the university through email and posters. Potential panelists were asked to complete an online demographic on the university website: http://www.uwindsor.ca/paint. Chrysler's sales record data was used to select a group of 60 participants for silver paint panel evaluation with a age group make-up similar to the vehicle–buying public, and participants were chosen on a first come first served basis. The number of panelists was reduced from 60 to 30 participants for white and blue paint panel evaluation, due to time constraints, and after verifying that fewer panelists would not affect the rank (Section 3.3.3).

Demographic data was obtained from the community profile of Canada (Statistics Canada, 2001) and data acquired from Maritz Canada Research (Source: ARDC, 2007). While selecting a sample for visual evaluation of paint panels; the age, gender, martial status and education profile of the past and potential customers present in the Canadian consumer market was considered along with other characteristics like their daily use of a car, eye-glasses and their knowledge about automotive paint. A spreadsheet containing an estimate of sample size for each age as well as education category is presented in Appendix K.

Every participant who completed the online survey was assigned a unique respondent number. Similarly the age, gender, education, martial status, car use, use of eye-glasses and knowledge of automotive paints were also designated by a key number to help in the analysis of demographic data's influence on overall appearance (Appendix M). Table 3 below illustrates the assigned key values for different attributes of the demographic data.

Table 3: The key values used in entering demographic data in the spreadsheet.

Gender	Male - 1	Female -2	
Age	18 to 40 years – 1	41 to 50 years - 2	51 years and above- 3
Education	High/ Tech. School – 1	Undergraduate – 2	Graduate/Post graduate – 3
Martial Status	Single – 1	Married – 2	
Daily car use	Yes – 1	No – 0	
Use of eyeglasses	Yes – 1	No – 0	
Knowledge of Automotive paint	No – 0	Some experience – 1	Expert - 2

3.3.3 Procedure

The selected paint panels were labeled on the back and cleaned. Each panelist was invited individually to the study room, to evaluate the paint panels. Throughout the study, the researcher handled the paint panels with gloves to avoid any fingerprints on the paint panel. The panels were cleaned with iso-propyl alcohol wipes after every session. The panelist evaluated each paint panel, as it was introduced one-at-a-time. As each new paint panel was introduced, the panelist decided where the additional paint panel ranked in terms of appearance, based on what they thought was desirable on a vehicle that they would buy. Subsequently, each paint panel was introduced into the ordered set of paint panels one at a time and the panelists decided where the paint panel would go.

After the last panel was placed in the sequence, the paint panel with the best appearance was ranked one and the paint panel with worst appearance was designated a rank of 16 or 10 or 14, depending on the set. After arranging the paint panels in order from best to worst, a "cut off" rank was determined each panelist by having them state which panel represents the minimum acceptable finish quality (all paint panels of a lower rank were considered acceptable too).

The Wilcoxon rank sum test is a nonparametric test, which employs the sum of ranks principle to determine whether the two samples are from the same distribution. (Anderson. R. et al., 1991). This test was performed after 60 panelists ranked the silver paint panels to verify if a representative sample of 30 participants (instead of 60) could be used in further tests. The median ranks of the 16 panels determined using 60 panelists were compared with those using a sub–set of 30 panelists. The calculated Z value (0.17) is less than the critical Z value for $\alpha=0.05$ (1.96), which indicates that the samples are not statistically different. The same conclusion was reached regardless if the 30 panelists selected were first 30 (of 60 panelists), the last 30 or randomly selected. A sample calculation is given in Appendix B.

CHAPTER 4 - Results and Discussions

4.1 Summary of data

The results gathered from the research study for each of the paint panels are tabulated in Appendix L and also a summary table can be found in Appendix C. During statistical analysis, data can be of a quantitative (measurement) or qualitative (categorical) nature. In this investigation, the predictor variables (Du, Wa, Wb, Wc, Wd and We) are quantitative data while the values for the dependent variable (rank) are qualitative (Anderson et. al., 1991).

Often during the examination of data, an observation that lies normally distant from the rest of the data is referred to as an outlier. Likely sources of outliers are data recording error, faulty procedures or chance. Since ranking is subjective, extreme values are anticipated and thus outliers present in this research study were not excluded from further analysis. However, since the mean rank is more influenced by outliers, the median rank was selected for further statistical analysis.

The observed ranks of silver, white and blue paint panels were tested to see if they were conformed to a particular distribution. The Anderson-Darling statistic (A^2) and P – value were used to determine the sustainability of a particular distribution. The smaller the A^2 value, the better the data fits the distribution. The null hypothesis, which states that the sample data are derived from the particular distribution, is accepted or rejected based on the P – value. The P – value is the probability that we obtain the observed value of the test statistic, or a value that is more extreme in the direction of the alternative hypothesis, calculated when Ho (the null hypothesis) is true (Hogg & Tanis 1996). Although ordinal data usually follow non-normal distribution, it is evident that the rank data for the silver panels in this study has a Normal distribution since the Anderson Darling co-efficient has the lowest value and the P – value is the highest for all distributions (Minitab, 2008) tested (Table 4). The detailed results of the distribution identification test are presented in Appendix D.

Table 4: Distribution identification for ranks of silver paint panels.

* = undetermined

Distribution	Anderson Darling Co-efficient	P-values
Normal	**0.307**	**0.524**
Box-Cox Transformation	0.324	0.494
Lognormal	0.368	0.386
3-Parameter Lognormal	0.354	*
Exponential	4.122	<0.003
2-Parameter Exponential	0.957	0.066
Weibull	0.313	>0.250
3-Parameter Weibull	0.471	0.253
Smallest Extreme Value	0.370	>0.250
Largest Extreme Value	0.417	>0.250
Gamma	0.370	>0.250
3-Parameter Gamma	0.376	*
Logistic	0.353	>0.250
Loglogistic	0.398	>0.250
3-Parameter Loglogistic	0.357	*

4.2 Paired t-tests

The paint panels were measured before and after visual evaluation by Wave-Scan DOI to determine if there was any significant change in contrast values after handling of the paint panels. The two sets of measurements were compared using a paired t–test (Beaver et. al., 1999) and the result for silver, white and blue paint panels are shown in Figures 11, 12 and 13 respectively. Data used to develop paired t-tests are located in Appendix M. The figures indicate that the changes in the panels are minor. In addition, paired t–tests comparing the before and after contrasts indicate all colors and structure sizes were not significantly different at the alpha = 0.05 level. As a result, the null hypothesis which states that there is no difference between the before and after readings is not rejected. A more detailed test result is presented in Appendix E.

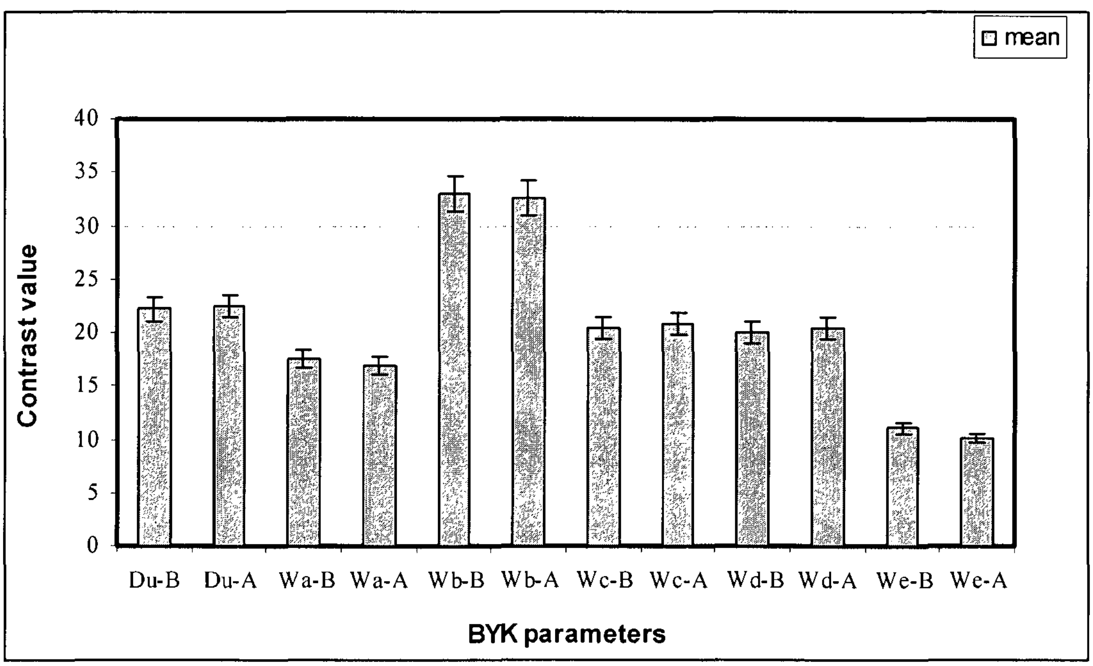


Figure 11: Summary of readings of BYK parameters for silver paint panels before and after evaluation by panelists.

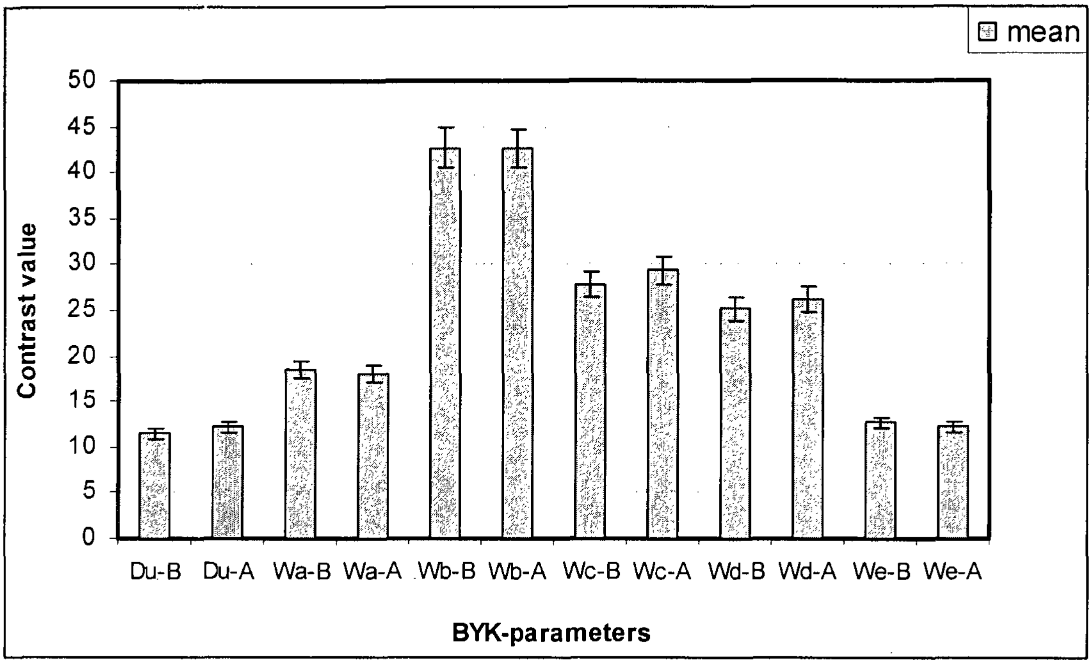


Figure 12: Summary of readings of BYK parameters for white paint panels before and after evaluation by panelists.

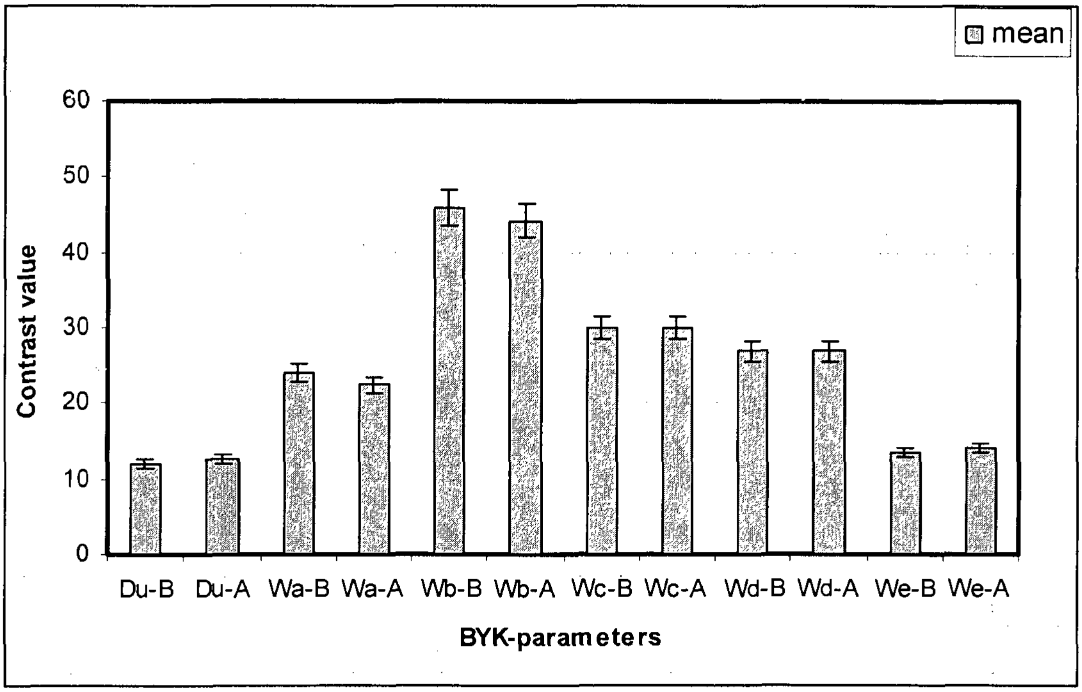


Figure 13: Summary of readings of BYK parameters for blue paint panels before and after evaluation by panelists.

In addition, a paired t-test was performed on the demographic data to find whether the median rank of paint panels is influenced by gender, age education and knowledge of automotive paint. From this paired t–test, it was found that the absolute value of the calculated test statistic was less than the critical t-value; hence, the test fails to reject the null hypothesis, which states that there exists no difference between the two samples. The reason behind this result could be the smaller sample size of some populations. For example, there were only a few panelists who had some expertise in paint, while the majority of them were not very familiar with paint finish quality. The results of these paired t test are tabulated in Appendix N.

4.3 Concordance of panelists

Each set of paint panels of three different colors were independently judged by a group of thirty panelists during the evaluation study. None of the panelists judged all three colors, and a few judged two colors. The final rank data obtained from the panelists for all the three groups of paint panels (silver, white and blue) were investigated individually to find if there was any significant agreement in rankings among the paint panels of the same color by all the thirty assessors. According to Kendall agreement criteria, the calculated $\hat{w}$ varies from 0 to 1; a $\hat{w}$ value of 1 indicates the existence of a high degree of agreement and 0 represents no overall trend of agreement among the respondents (Moroney, 1958). According to the calculations shown in Appendix O, the rankings of white and blue paint panels have values of 0.582 and 0.579, indicating a fairly significant agreement among the panelists. On the other hand, the silver paint panels had the least concordance (0.105) between the rank assigned by the panelists.

To develop a set of standards for an instrument it is of utmost importance to find a threshold/cutoff value of the measurable parameter that influences the criterion i.e., rank. When the participants arranged the paint panels in accordance to their liking, they also selected a panel that denotes a minimum acceptable panel, beyond which they usually disliked the paint panel coating. Plots of the percentage of panelists cut off values as functions of contrast values in each structure size category (Du, Wa, etc.,) are in Appendix J. While some of these histograms show a narrow range of cut-off values (eg. Du, Wa, Wd and We for silver) others (white and blue) are spread out and inconsistent. Initially a cumulative frequency plot was used to determine the "cut off" value for each BYK structures size category for each of the three color groups. It is misleading to assume that the cut off values can be cumulated. An example of the ranking and cut off pattern of paint panels for two panelists is shown in Table 5. The panels (leftmost column) are arranged in order of ranking according to panelist #12. Panelist #12 believed that panel 11 (and all panels of a lower rank) are acceptable. However, none of the contrast values, in any structure size category consistently increase or decrease in the rows above panel 11. Panelist #373 decided that only the top two panels were acceptable. It is impossible to rationalize these different rankings into one cut off value for any structure size category.

Table 5: An example of the ranking and minimum acceptable panel of the paint panels by two panelists

ID	panelist#12	panelist#373	Du	Wa	Wb	Wc	Wd	We	LC	WL
Panel 4	1	6	29.18	17.30	38.06	15.98	17.06	10.92	0.38	0.03
Panel 10	2	11	22.30	19.04	38.74	21.58	20.30	11.94	0.31	-0.03
Panel 6	3	7	19.10	21.16	33.22	19.14	20.32	12.64	0.24	0.03
Panel 1	4	9	18.20	18.52	30.58	21.50	20.00	10.44	0.21	-0.04
Panel 18	5	10	19.16	15.90	29.36	19.26	17.00	6.94	0.27	-0.06
Panel 12	6	5	22.96	15.54	32.34	14.30	16.58	9.82	0.32	0.07
Panel 15	7	4	27.12	16.12	35.24	16.42	14.92	8.00	0.41	-0.05
Panel 3	8	2	26.36	15.88	33.84	18.62	17.56	8.78	0.32	-0.03
Panel 5	9	3	23.46	12.42	27.78	16.74	17.98	10.10	0.21	0.04
Panel 11	10	1	26.26	22.34	42.30	21.24	17.46	10.56	0.42	-0.09
Panel 19	11	8	24.74	16.84	36.18	20.72	19.34	14.44	0.30	-0.03
Panel 8	12	15	20.66	12.86	23.80	17.90	22.72	13.54	0.02	0.12
Panel 13	13	13	19.08	18.96	33.52	22.92	19.86	11.80	0.26	-0.07
Panel 14	14	12	18.64	19.34	31.50	30.10	24.80	11.14	0.12	-0.09
Panel 16	15	14	18.96	18.18	30.82	25.86	25.02	10.48	0.10	-0.02
Panel 17	16	16	19.74	19.32	30.54	23.26	29.12	15.70	0.02	0.1

The cut-off range could be estimated based on the maximum frequency. A summary of highest frequency cut off range for silver, white and blue paint panels are given in Table

6 along with the fraction of panelists selecting this category for each structure size category. In only three cases do the majority of panelists agree on an acceptable contrast value for a given structure size category. The corresponding graphs are given in Appendix G.

Table 6: Cut–off range of contrast values by BYK parameter for silver, white and blue paint panels

	Du	Wa	Wb	Wc	Wd	We
Silver	22 – 24 (33.3% of panelists)	18 – 20 (33.3% of panelists)	32 – 34 (30% of panelists)	20 – 22 (33.3% of panelists)	16 – 18 (40% of panelists)	10 – 12 (56.6% of panelists)
White	7.5 – 10 (66.6% of panelists)	12 – 14 (46.6% of panelists)	42 – 44 (40% of panelists)	22 -24 30 – 32 36 - 38 (26.6% of panelists	27 – 28 (26.6% of panelists)	13 – 14 (25.3 % of panelists)
Blue	11 – 12 (33.3% of panelists)	22- 23 (33.3% of panelists)	47 – 48 (33.3% of panelists)	23 – 24 (33.3% of panelists)	23 – 24 (50% of panelists	14 – 15 (44.3% of panelists

4.4 Regression analysis

In this regression analysis, the "before" visual evaluation BYK readings were used. As reported earlier, apart from Du, Wa, Wb, Wc, Wd and We; longwave coverage (LC) and wet look (WL) are reported by BYK to heavily influence the overall appearance of the coating. Hence LC and WL were also integrated in the regression analysis.

Regression Analysis is a statistical tool used in identifying the relationship between independent and dependent variables and may be further used in developing a forecasting model. In regression analysis, the measure of total variation (SST) is the sum of squares of explained variation (SSR) and sum of squares of unexplained variation (SSE). The proportion of total variation (SST) that is explained by the regression (SSR) is known as the Coefficient of Determination, and is often referred to as R-Sq. Since there are several predictor variables in this study a multiple regression analysis method was conducted. It is a well known fact that the R-sq value tends to be increase by the inclusion of more and more independent variables, but some of the variables do not contribute much to the model. Hence, the "Adjusted R –Sq" is used in multiple regressions since it takes into account the size of the sample and number of explanatory variables and gives accurate information about multiple regression models.

The main objective of this research study was to determine the criterion variables from a set of predictors; hence backward and forward selection procedures (regression) were used to select the predictor variables. The forward selection procedure (regression) initially starts with the independent variable associated with the lowest P – value arising when the dependent variable is regressed against that independent variable. A similar process is followed for the other predictor variables that were not included; they are added one at a time into the model and the one with the lowest P – value is added to the model. The forward selection procedure (regression) proceeds until in the subsequent rounds the lowest predictor variable P – value is greater than the alpha value specified, then the forward stepwise procedure will stop.

The backward selection procedure (regression) initiates with all independent variables in the model. The procedure eliminates the variable with the largest P – value, i.e., the variable which contributes least towards the model fit. The same step is repeated for the remaining variables present in the model. The backward regression ceases when all the co–efficients remaining in the model are statistically significant i.e., P – value less than alpha value. The detailed results of forward and backward regressions can be found in Appendix F. There were predictor variables that were common for backward and forward regression and a few independent variables unique to either backward or forward regression. Table 7 shows the variables for three different color groups of paint panels.

The *best subset* regression was utilized to identify the predictor variables which were not common to forward and backward regression but improved the models. The best-subset regression examines the best combinations of predictor variables from all possible models. The model with largest R-Sq (Adjusted) and smallest value of Mallow's C–p is selected as the best fit regression model.

Table 7: Significant predictor variables from forward and backward regressions.
Uncommon predictor variables are found in either forward or backward regression, but not in both.

	Common predictor variable	**Uncommon predictor variable**	**Added in sub setting**	**R – Sq Adj**	**Mallows C-p**
Silver	Wb, Wc, We, WL, LC	Wd		73 %	
White	Du, Wa, Wb	Wc, Wd, We, LC, WL	Wd, LC	78.1%	4
Blue	Wc, Wd, WL	Du, Wa, Wb, We,	Du, Wa	23.4%	4.9

4.4.1 Silver – model summary

From the backward and forward regression it was found that Wb, Wc, We, LC and WL were the significant independent variables influencing the median rank of silver paint.

Through Subset regression it was found that inclusion of any other predictor variable would not yield a better fit model. Hence a best fit model, with median rank as the dependent variable and Wb, Wc, We, LC and WL as predictor variables were subjected to further regression analysis.

The regression co – efficients for the analysis of silver paint panels are shown in Table 8. It is evident from the Table 8 that Wc, Wb, WL and LC are the most important variables influencing the median rank, since all their P – values are < 0.05.

Table 8: Regression coefficients of silver paint panels

Predictor	**Coefficient**	**SE Coefficient**	**T-value**	**P – value**
Constant	-11.374	6.249	-1.82	0.099
Wb	-1.0714	0.3459	-3.10	0.011
Wc	1.6787	.4813	3.49	0.006
We	0.5244	0.2476	2.12	0.060
Longwave coverage (LC)	65.30	22.68	2.88	0.016
Wet look (WL)	66.18	21.38	3.10	0.011
S = 1.17638 R-Sq = 82.0% R-Sq (Adjusted) = 73.0%				

The R-Sq value of 82% and adjusted R-Sq value of 73% means that only 82% of the variance in the ranking of paint panels can be predicted by Wave-scan attributes. With an F – ratio of 9.13 and P – value of 0.002 (Table 9), we can except that the model can explain the effects of the predictor variable on the response.

Table 9: ANOVA results for rank predictor model of silver paint panel model

Source	Degree of Freedom	Sum of squares	Adjusted mean squares	F–value	P – value
Regression	5	63.146	12.629	9.13	0.002
Residual Error	10	13.839	1.384		
Total	15	76.984			

As stated earlier the overall appearance may also be influenced by chromatic characteristics, although these panels were painted with same basecoat. However, due to the high concentration of metallic flakes in the paint, and the fact that the flake orientation (and hence brilliance of the panel) is influenced by paint application process parameters, there may be some variability in the lightness of the panels, which may have influenced the panelist's ranking. To determine if lightness (and indeed color) was a significant factor, the median rank was regressed against the L*, a* and b* values of the panels, as determined before human evaluation. It is evident from the value of R– Sq in Table 10 that only 39.4% of the variation can be explained when all of the variables are included in the regression. The lightness (L*) is the most significant variable in the regression analysis with a P – value of 0.053 which is slightly over the alpha level of 0.05. In spite of this, the lightness variable was included along with Wc, Wb, WL and LC to find if it does make a contribution in the prediction of the rank. From the regression analysis (Table 11) we find that Lightness is not a significant factor in predicting the overall appearance of paint panel (P = 0.913). Furthermore, the R-Sq stayed the same as for the regression without L* (82.0%) and the R-Sq (adjusted) decreased to 70.1%.

Table 10: Regression co-efficients of L* a* b* to rank for silver paint panels

Predictor	Coefficient	SE Coefficient	T - value	P - value
Constant	-45.08	27.14	-1.66	0.123
L*	0.6356	0.2955	2.15	0.053
a*	-19.03	10.76	-1.77	0.102
b*	-5.397	5.129	-1.05	0.313
S = 1.763 R-Sq = 51.6% R-Sq (Adjusted) = 39.4%				

Table 11: Regression coefficients of L* and BYK parameters for silver paint panels

Predictor	Coefficient	SE Coefficient	T - value	P - value
Constant	-12.20	10.06	-1.21	0.256
L*	0.0127	0.1167	0.11	0.916
Wb	-1.0670	0.3666	-2.91	0.017
Wc	1.6712	.5116	3.27	0.010
We	0.5219	0.2619	1.99	0.077
Longwave coverage (LC)	65.39	23.91	2.73	0.023
Wet look (WL)	66.19	22.52	2.94	0.017
S = 1.123920 R-Sq = 82.0% R-Sq (Adjusted) = 70.1%				

4.4.2 White – model summary

From the backward and forward regression of white paint panels, Du, Wa, Wb were most found to be the most significant common variables. Through subset regression it was found that Wd and LC should be added to the best fit regression model. Analysis of the white paint panel regression revealed that a high co – efficient of multiple determination

(R-Sq) of 78.1 %, indicating there is a strong relationship between the change of rank and Wave-scan variables. This is also means that 21.9% of the variance is unexplained. It is evident from the Table 16 that the model is a best fit model since the overall P – value of the white paint model is found to be 0.037, which is less than the alpha value. Summaries of the regression analysis of white paint panels are found in Tables 12 and 13.

Table 12: Regression coefficients for rank predictor model of white paint panels

Predictor	Coefficient	SE Coefficient	T - value	P - value
Constant	-7.504	3.608	-2.08	0.106
Du	-0.92324	0.3239	-2.85	0.046
Wa	1.0933	.3027	3.61	0.023
Wb	-1.7352	.4106	-4.23	0.013
Wd	2.2113	.5293	4.18	0.014
Longwave coverage (LC)	90.21	20.46	4.41	0.012
S = 1.023 R-Sq = 90.3% R-Sq (Adjusted) = 78.1%				

Table 13: ANOVA results for rank predictor model of white paint panel

Source	Degree of Freedom	Sum of squares	Adjusted mean squares	F - value	P - value
Regression	5	38.913	7.783	7.44	0.037
Residual Error	4	4.187	1.047		
Total	9	43.100			

Five of the independent variables (Du, Wa, Wb, Wd, LC) are considered significant when predicting the rank of white paint panels. Wb was the most significant variable with a P –

value of 0.013. The proposed model for white paint panel accounts for 90.3% of the variance in predicting median rank.

Table 14 summarizes the regression analysis test of the white paint panels' rankings with their chromatic characteristics. The R – Sq value of 30.4 % and R-Sq (adj) value of 0.0% indicate a weak correlation between the rank and the L* a* b * values of white paint panels (Fitz-Gibbon, C. T., & Morris, L. L., 1987).

Table 14: Regression coefficients of L* a* b* to rank for white paint panels

Predictor	Coefficient	SE Coefficient	T - value	P - value
Constant	-179.2	459.1	-0.39	0.710
L*	2.550	4.848	0.53	0.618
a*	7.40	21.99	0.34	0.748
b*	-6.455	7.302	-0.88	0.411
S = 2.235 R-Sq = 30.4% R-Sq (Adjusted) = 0.0%				

4.4.3 Blue – model summary

During the backward and forward regression it was found that Wc, Wd, and WL were the most influential variables. From sub-setting, it was also found that Du and Wa were influential in predicting the overall rank of a blue paint panel. Table 15 reveals a moderately low co-efficient of multiple determination, R- Sq at 23.4%, indicating weak relationship between the rank and the predictor variables. This leaves 76.6% of the variance unexplained. With an F – ratio of 1.79 and P – value of 0.220, it is evident the model obtained is weak and it fails to predict the rank of the blue paint panels (Table 16).

Table 15: Regression coefficients for rank predictor of blue paint panels

Predictor	Coefficient	SE Coefficient	T - value	P - value
Constant	-14.98	11.62	-1.29	0.234
Du	-0.8770	0.4573	-1.92	0.091
Wa	0.6598	0.3245	2.03	0.076
Wc	-5.119	2.033	-2.52	0.036
Wd	5.798	2.325	2.49	0.037
Wet look (WL)	-254.1	110.2	-2.31	0.050
S = 1.7957 R-Sq = 52.9% R-Sq (Adjusted) = 23.4%				

Table 16: ANOVA results for rank predictor model of blue paint panels

Source	Degree of Freedom	Sum of squares	Adjusted mean squares	F – value	P - value
Regression	5	28.934	5.787	1.79	0.220
Residual Error	8	25.798	3.225		
Total	13	54.732			

The blue paint panels were also subjected to regression analysis with color variables namely L* a* b*. The resulting model indicated a poor correlation between the rank and the chromatic variables. Regression co-efficients for blue paint panels are shown in Table 17. Clearly, wave–scan contrast values and changes in color do not have a great influence on people's perception of blue painted panels. Anecdotal evidence from panelists during the evaluation suggests that people like the color, so changes in the surface undulations were inconsequential.

Table 17: Regression coefficients of L* a* b* to rank for blue paint panels

Predictor	Coefficient	SE Coefficient	t-value	P – value
Constant	-179.2	459.1	-0.39	0.710
L*	2.550	4.848	0.53	0.618
a*	7.40	21.99	0.34	0.748
b*	-6.455	7.302	-0.88	0.411
S = 2.235 R-Sq = 30.4% R-Sq (Adjusted) = 0.0%				

A summary of the final model of silver, white and blue paint panel obtained from regression analyses are presented in Table 18.

Table 18: Final rank predictor models for silver, white and blue paint panels

Color	Equation for median rank	R-Sq
Silver	- 11.4 - 1.07 Wb + 1.68 Wc + 0.524 We + 65.3 LC + 66.2 WL	82.0%
White	- 7.50 - 0.923 du + 1.09 Wa - 1.74 Wb + 2.21 Wd + 90.2 LC	90.3%
Blue	- 15.0 - 0.877 du + 0.660 Wa - 5.12 Wc + 5.80 Wd - 254 WL	30.4%

4.4.4 Model adequacy checking

Residual Analysis is very effective way to investigate the adequacy of the fit of a regression model and to check the underlying assumption of normality.

Normal probability plot of residuals:

Probability plotting is a graphical method for determining whether data conform to the hypothesized distribution based on the subjective visual examination of the data. During the analysis, the plots of the residual of each observed value against calculated values of that residual are plotted.. The normal probability plot of silver, white and blue paint panels lie reasonably close to a straight line. The probability plots are shown in the Figures 14, 15 and 16.

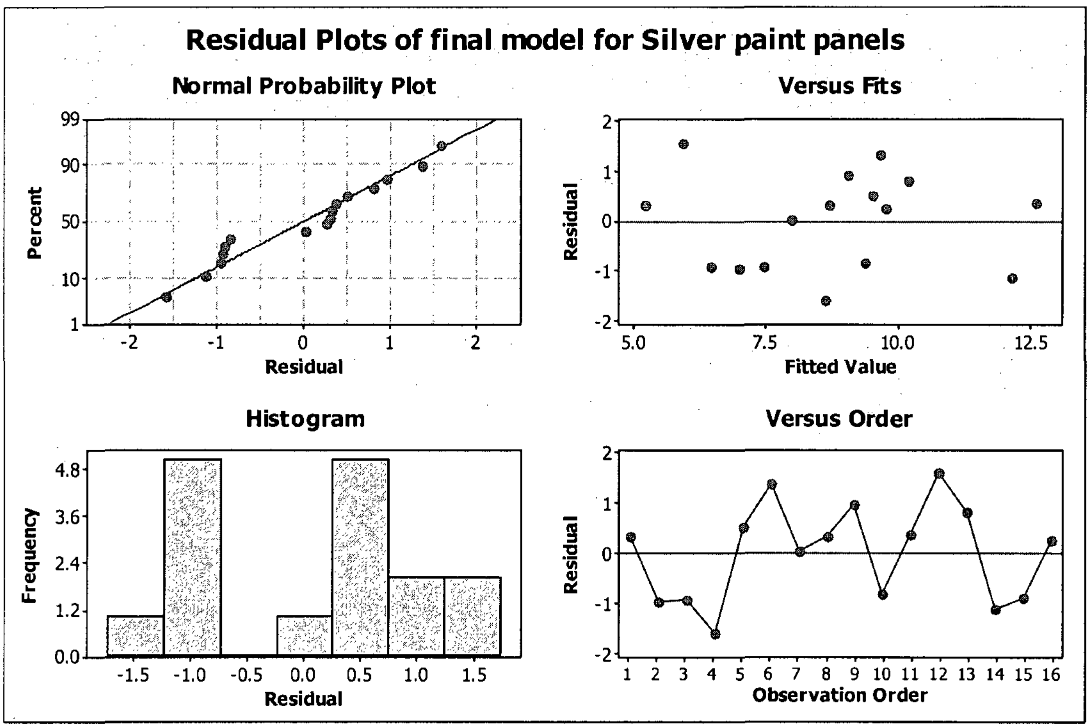


Figure 14: Residual analysis of regression model for silver paint panels

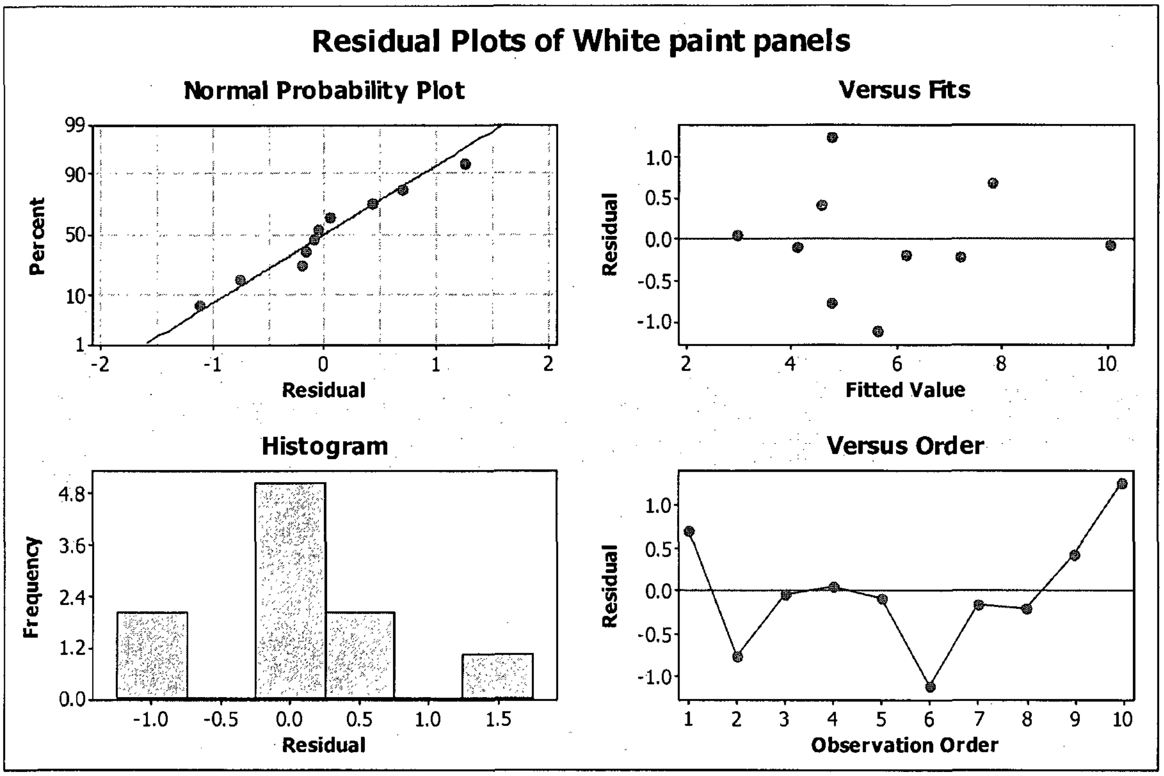


Figure 15: Residual analysis of regression model for white paint panels

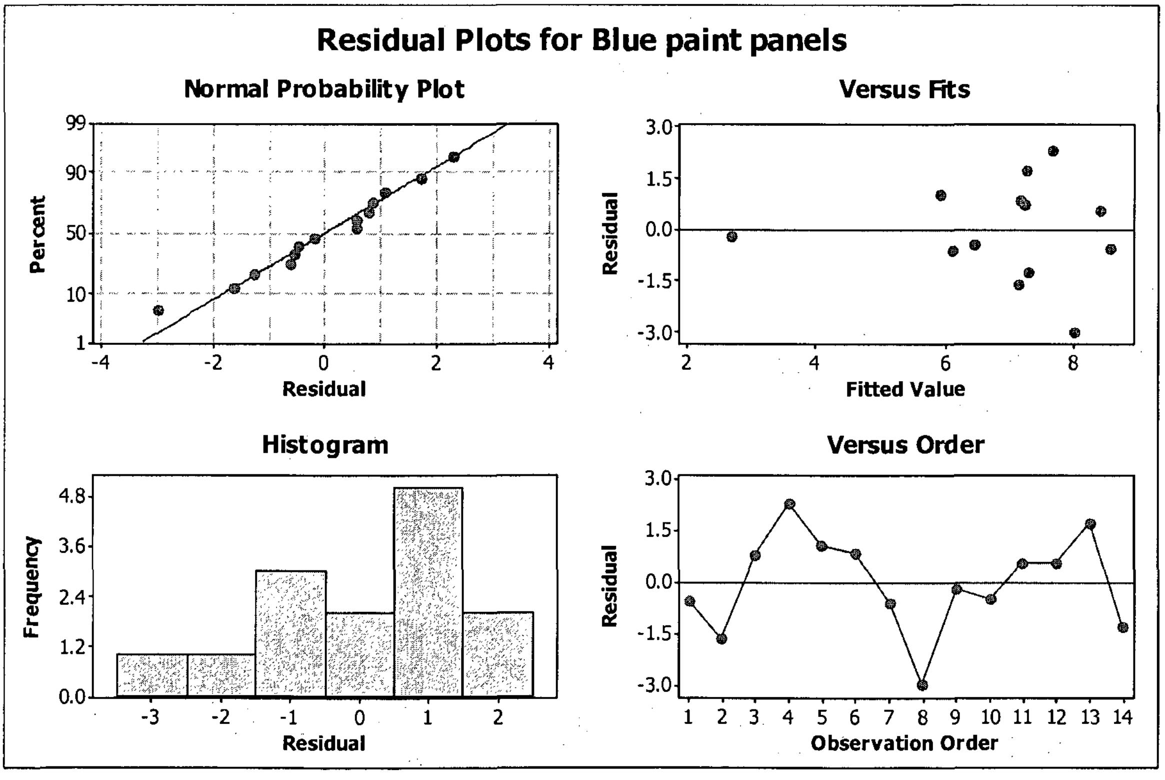


Figure 16: Residual analysis of regression model for blue paint panels

Residual Plots:

The residual plot shows the difference between measured and calculated value of dependent variable (rank). If the regression model is appropriate, the plots of regression residuals versus predicted and versus observed values must not exhibit a pattern around the line of error = 0 and must have zero mean. In the residual plots of silver, white and blue shown in Figures 14, 15 and 16; no obvious pattern were identified. Therefore it can be concluded that there is no reason to suspect any violation of independence or constant assumption.

4.4.5 Multicollinearity

A correlation matrix was calculated to determine whether the independent variables are collinear or correlated. The correlation matrices of silver, white and blue are given in Tables 19, 20 and 21 respectively.

Table 19: Correlation matrix for Wave-scan characteristics of silver paint panels

	Median	Du	Wa	Wb	Wc	Wd	We	LC	WL
Median	1								
Du	-0.57865	1							
Wa	0.087862	-0.17972	1						
Wb	-0.42301	0.579636	0.621085	1					
Wc	0.525543	-0.57367	0.532469	-0.00745	1				
Wd	0.742565	-0.61766	0.258714	-0.37079	0.709568	1			
We	0.591622	-0.22007	0.233819	-0.05412	0.279433	0.672932	1		
LC	-0.71973	0.717384	0.15279	0.773274	-0.48347	**-0.8691**	-0.50595	1	
WL	0.307958	-0.02915	-0.43375	-0.50018	-0.44402	0.303529	0.465143	-0.46931	1

Table 20: Correlation matrix for Wave-scan characteristics of white paint panels

	Median	Du	Wa	Wb	Wc	Wd	We	LC	WL
Median	1								
Du	0.648979	1							
Wa	0.619856	0.950704	1						
Wb	0.472186	0.655191	0.795189	1					
Wc	0.44188	0.598428	0.612684	**0.803801**	1				
Wd	0.312957	0.475387	0.466649	0.599981	0.930033	1			
We	0.466342	0.68995	0.714315	0.774307	0.90899	0.9091	1		
LC	0.441999	0.431865	0.577347	**0.846888**	0.466171	0.146847	0.374624	1	
WL	-0.49626	-0.555	-0.58956	**-0.87772**	**-0.89427**	-0.67845	-0.72663	-0.76621	1

Table 21: Correlation matrix for Wave-scan characteristics of blue paint panels

	Median	**Du**	**Wa**	**Wb**	**Wc**	**Wd**	**We**	**LC**	**WL**
Median	1								
Du	-0.02385	1							
Wa	0.070104	0.962713	1						
Wb	0.182569	0.634961	**0.775404**	1					
Wc	-0.20994	-0.49731	-0.51769	-0.5713	1				
Wd	-0.14746	**-0.72566**	**-0.74873**	-0.6946	0.943978	1			
We	-0.22004	-0.26111	-0.25902	-0.01293	0.02581	0.141431	1		
LC	0.163583	**0.756685**	**0.840203**	0.908426	**-0.82887**	-0.92748	-0.11103	1	
WL	0.079283	**-0.82035**	**-0.82237**	-0.48192	0.078815	0.400693	0.387312	-0.48532	1

When two or more independent (predictor) variables in multiple regressions are correlated, we describe this phenomenon as multicollinearity. Such high correlation creates problem when trying to draw inference about the relative contribution of each predictor variable to the success of the model. When the correlation between two independent variables is greater than 0.9, this indicates the existence of multicollinearity in the model. These values are darkly shaded in tables 19 to 21. A correlation value greater than 0.80, means these variables are said to have "near multicollinearity" (Licht, 1995).

Multicollinearity exists between Wd-Wc and Wa-Du, in white and blue paint panels respectively. A high correlation in contrast values between adjacent structure sizes is not unexpected. An application processes which leads to surface undulations of 0.1mm wavelength might be expected to affect Du and Wa, so there would be a correlation between these two.

Mathematically, LC is a function of Wb and Wd, so one could expect a high correlation between LC and these. Indeed, there exists multicollinearity between LC and Wb and between LC and Wd in the blue panels. However, only near collinearity exists between LC and Wb in white panels, and between LC and Wd in silver, No collinearity involving LC exists otherwise. If the mathematical relationship was important, there would exist multicollinearity between all LC and Wb or Wd.

Furthermore, the correlation between WL and Wc or WL and Wd is minimal (only an R^2 of 0.89 between WL and Wc for white, otherwise less than 0.5), further reinforcing the independence between WL, LC and their component variables.

Although many mitigating measures such as extending the sample size, transferring the function relationship and dropping one of the highly correlated variables are suggested by various mathematicians, an appropriate alternative and consensus among statisticians regarding how to counter multicollinearity is yet to be found.

4.4.6 Coding

Coding provides one way of using categorical predictor variables in various kinds of estimation models, such as regression. Coding involves assigning all predictor variables, a value in the range of 1 to -1. A coded value for each of the independent variable is calculated by using an equation below:

$$\text{Coded value} = \frac{(\text{Actual value} - \text{Midpoint of Actual range})}{(\text{Half of Actual range})}$$

Coded factors play an important role in the analysis of data; they provide a high degree of flexibility in selecting a modeling methodology. Since all the predictor variables are converted to the same arbitrary units during coding, the co-efficient of the resulting model can be used directly for assessing the effects of independent variables based on the resulting magnitude of the coefficients associated with the coded factors (Evans & Evans, 2001 and Zielinski, 2004). Using coded values, the predictor variable with the highest co–efficient is considered to have the most significant effect on the response variable.

The variables used for the coded models were those used in the final regression model (Table 10). A summary of the final models for silver, white and blue paint panels using coded factors are shown in Table 22.

Table 22: Final rank predictor models of silver, white and blue paint panels using coded factors. The prime (') identifies coded variables.

Color	Equation for median rank
Silver	11.4 – 9.91 Wb' + 13.3 Wc' + 2.30 We' + 12.8 LC' + 7.16 WL'
White	3.68 – 12.9 Du' + 22.9 Wa' – 36.8 Wb' + 10.9 Wd' + 19.7 LC'
Blue	1.62 – 5.86 Du' + 7.60 Wa' – 47.0 Wc' + 49.3 Wd' – 17.4 WL'

Earlier, the selection of predictor variables was based on their p – value. The importance of these variables was confirmed by the highest coded value co-efficient as well. A graphical description of the result obtained by the selection procedure based on P – values and a coded factor is depicted in Figures 17-19. In these figures, the lower the P – value, the more significant the variable. Also shown are the absolute values of the inverses of the coded predictor co-efficients. The inverse is plotted so that, similar to P – values, the lower the value, the more important the variable.

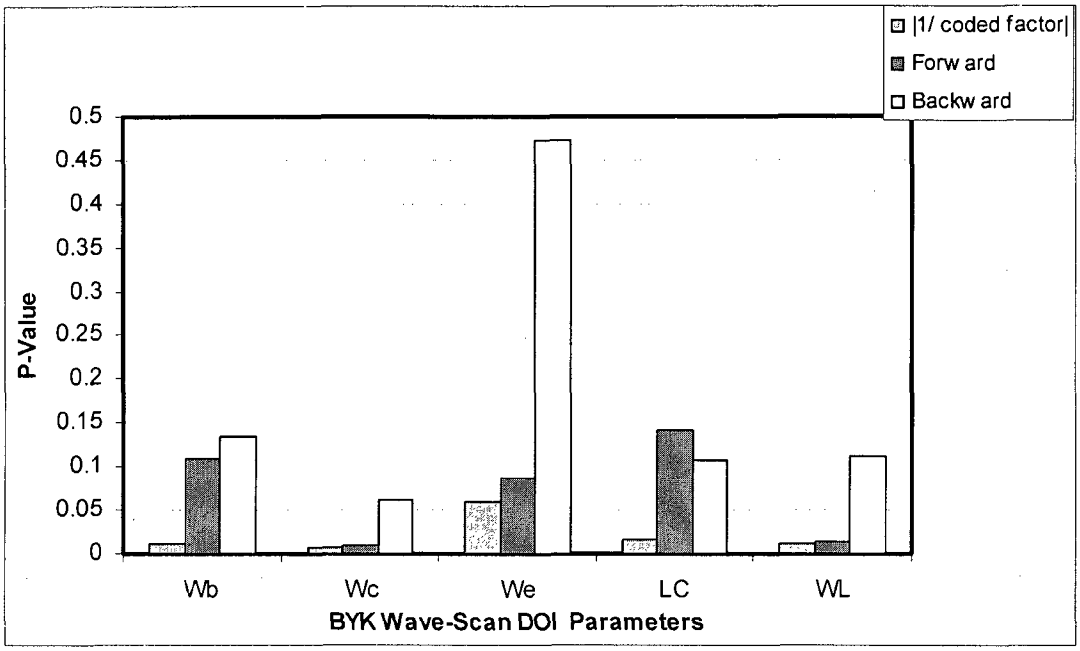


Figure 17: Comparison of significance of predictor variables for silver paint panel rank

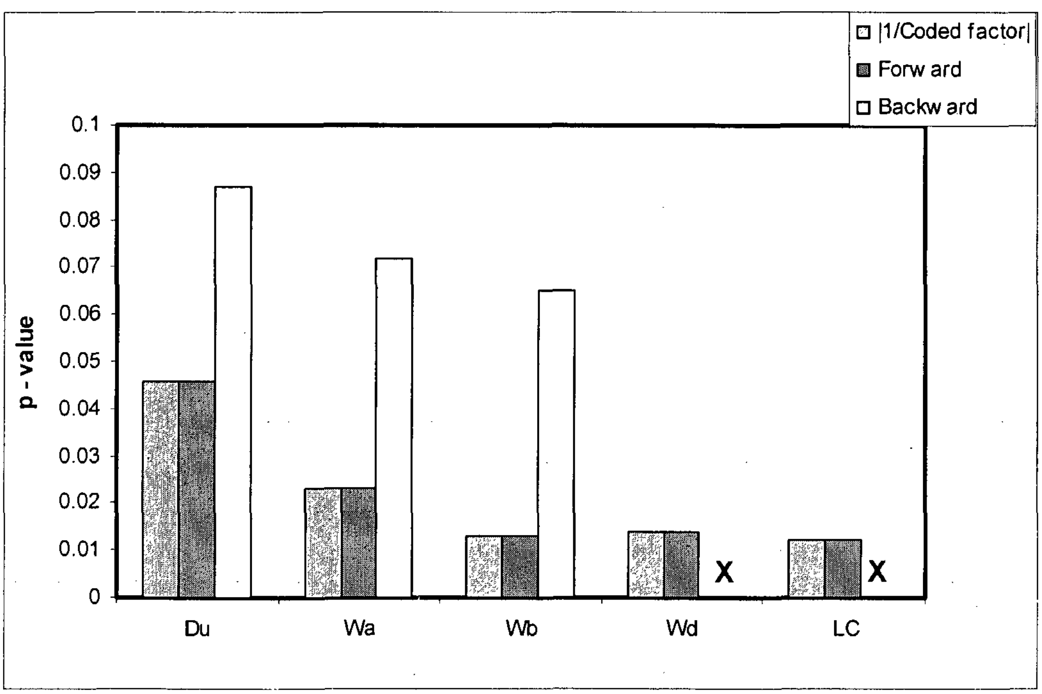


Figure 18: Comparison of significance of predictor variables for white paint panel rank (X= not included in the backward regression)

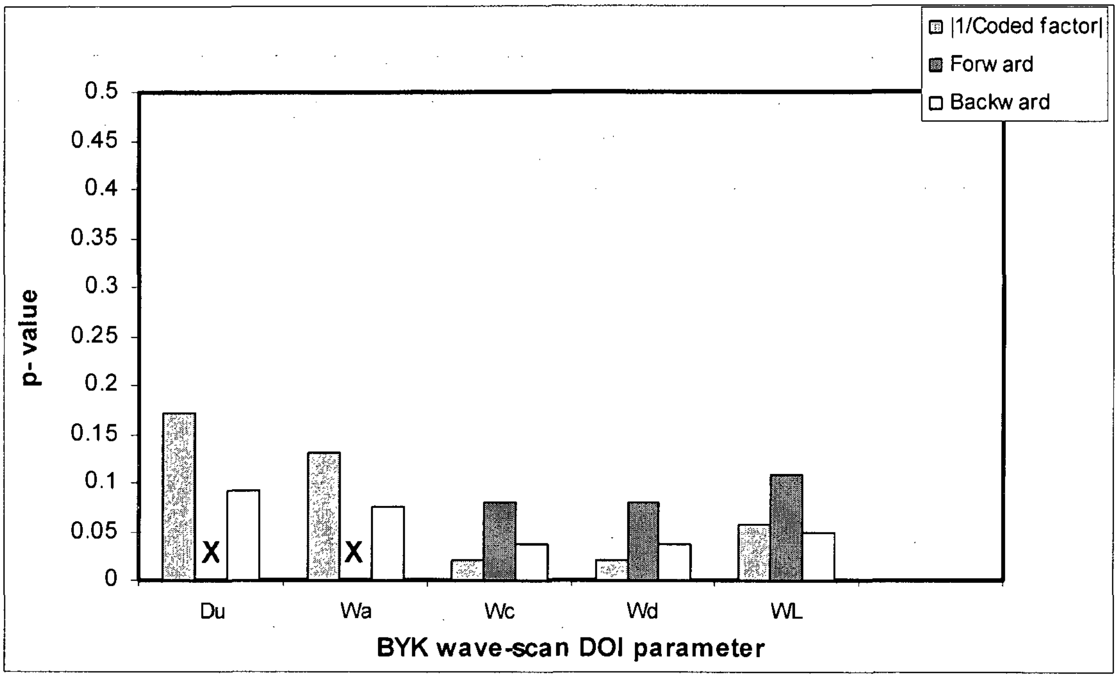


Figure 19: Comparison of significance of predictor variables for blue paint panel rank (X= not included in the forward regression)

Coding was implemented for silver, white and blue paint panel models. Factors which were both significant ($p < 0.05$) and influential (low 1/coded value) can be quickly selected from these graphs. For silver, Wc and WL have low p – values and relatively low inverse coded values. For white, there were no variables, which met the tests of $p < 0.05$ (from both forward and backward regressions) and had a 1/coded value in the lower half of the set of variables. For blue, again no variables were significant and important. However, the overall applicability of the model is low, due to the low adjusted R – Sq. The detailed result of the coded factors is given in Appendix H.

CHAPTER 5 – CONCLUSION AND RECOMMENDATIONS

5.1 Conclusions

This study demonstrates the applicability of using the Wave-scan DOI in determining the rating of overall appearance of automotive paint coatings.

- Wave-scan parameters were strongly correlated to rank for silver and white paint panels. High R-Sq values of 82% and 90% were obtained by regression analysis for silver and white paint panels respectively.
- Wb, Wc, We, longwave coverage and wet look were the most significant variables influencing the overall rank of silver paint panels, with Wc and WL was the most significant variables.
- The ranking of white paint panels were influenced by Du, Wa, Wb, Wd and longwave coverage.
- Although blue was one of the preferred colors among the paint panelists, the predictor model for blue paint panel was moderate since the R-Sq value was only 30%.
- Comparing the rankings with chromatic variables (L* a* b*), we find that participants were not influenced by color during visual evaluation of paint panels of the same color group.
- After eliminating non – significant variables, multicollinearity still existed in the white and blue paint panel models.
- The sample size of thirty resulted in no significant differences among the demographic groups with respect to ranking of the paint panels.

5.2 Recommendations

Based on the analysis of this research study, the following recommendations are made for further investigation:

- To investigate whether some demographic parameters have an influence, further studies must be carried out with at least 30 participants in each demographic group.
- An alternative must be investigated to reduce error due to multicollinearity encountered during regression analysis of ordinal data.
- The source of the change in the values of BYK parameters after handling of paint panels is unknown. An investigation must be carried out to find the reason for the change.
- A wider range of contrast values for Du, Wa, Wb, Wc, Wd, and We could be introduced, so that a clear distinction of which of these parameters have a potential effect on the overall rank could be determined
- An investigation into devising a method to find a minimal acceptable contrast value for each structure size category should be conducted.
- A visual evaluation for the same experiment with the same panels and panelists could be conducted to determine the repeatability.

References

Anderson, D. R., Sweeney, D. J., & Williams, T. A. (1991). Introduction to statistics: concepts and applications. St. Paul, MN: West Pub. pp. 636 – 642.

ASTM Standard D 1729, 1996 (2003), "Standard Practice for Visual Appraisal of Colors and Color Differences of Diffusely-Illuminated Opaque Materials" ASTM International, West Conshohocken, PA, www.astm.org.

ASTM Standard E284, "Terminology of Appearance" ASTM International, West Conshohocken, PA, [Online]www.astm.org. Accessed 01 Feb 2007

American National Standard Practice for Industrial Lighting, *Lighting Design and Application*, v 13, n 7, Jul, 1983, pp 29-68

AutoSpec- Profile (2006), [Catalog], Plymouth MI, USA. http://www.perceptron.com/news.html. Accessed 15 Dec 2006

Beaver, B. M., Mendenhall, W., & Beaver, R. J. (1999). *Introduction to probability and statistics, tenth edition.* Belmont, CA: Duxbury/Thomson Brooks/Cole. pp 651-653

DuPont Automotive's 2006, Continental Chroma, http://www.prnewswire.com/mnr/dupont/26213/. Accessed 12 Dec 2006

Evans, J. W., & Evans, J. Y. (2001). *Product integrity and reliability in design.* London: Springer. pp. 308 -309.

Fitz-Gibbon, C. T., & Morris, L. L. (1987). *How to analyze data.* Newbury Park, Calif: Sage Publications. pp. 82.

Fensterseifer F. (2004) Appearance of automotive finishes. 6th Wave-scan User Meeting, Konigsdorf, Germany: BYK-Gardner, Geretstried, Germany.

Geffen, C. A., & Rothenberg, S. (2000). Suppliers and environmental innovation: the automotive paint process. International Journal of Operations and Production Management. 20, 166-186.

Hanspeter Gradischnig (2004) First experiences with the wave scan DOI and correlation to the visual perception. 6th Wave-scan User Meeting, Konigsdorf, Germany: BYK-Gardner, Geretstried, Germany.

Hogg, R. V., & Tanis, E. A. (2006). *Probability and statistical inference.* Upper Saddle River, NJ: Prentice Hall. pp 352.

Hunter Associates, Technical Services, Insight of Color, Volume 13,No. 2, pages 1- 4.

http://www.hunterlab.com/appnotes/an02_01.pdf . Accessed 1 October 2008.

Kigle –Böckler, G. (2004) Milestones in the history of appearance control. 3rd Wave-scan User Meeting, Detroit, Michigan: BYK-Gardner, Columbia, USA.

Kigle–Böckler, G. (2004) Benchmark Study. 6th Wave-scan User Meeting, Konigsdorf, Germany: BYK-Gardner, Geretstried, Germany.

Lex, Konrad (Koenigsdorf, DE) (2005) Method and device for characterizing surfaces United States BYK-Gardner GmbH 20050046870. http://www.freepatentsonline.com/20050046870.html. Accessed 27 Mar 2008.

Konard Lex (2004), Advanced QC tool for process control – Structure Space. 3rd Wave-scan User Meeting, Detroit, Michigan: BYK-Gardner, Columbia, USA.

Licht, M. H. (1995). Multiple Regression and Correlation. In Grimm, L., & Yarnold, P. (Eds.), *Reading and understanding multivariate statistics*. Washington, D.C., American Psychological, Association. pp. 110-136.

Morland C., Mikec V., (2004) Visual perception of appearance and correlation to instrumental data. 6th Wave-scan User Meeting, Konigsdorf, Germany: BYK-Gardner, Geretstried, Germany.

Moroney, M.J. (1958). *Facts from figures* (3rd Edition), Harmondsworth, UK: Penguin Books Ltd.

Hill, T. (2004) Appearance of automotive finishes, 3rd Wave-scan User Meeting, Detroit, Michigan: BYK-Gardner, Columbia, USA.

Volatile Organic Compounds in Consumer and Commercial Products (2008), Automotive Refinishing Products, Environment Canada. http://www.ec.gc.ca/nopp/voc/en/secAR.cfm. Accessed 8 Aug 2008.

Zielinski, Kevin. (2004), Design of Experiments for Engineers, SAE Seminars ID#C0406, Troy, MI, USA.pp.220-225.

Appendix A: List of paint panels used for visual evaluation

Table A.1: Wave-scan characteristics of silver paint panels used for visual evaluation.

Panel ID	Du	Wa	Wb	Wc	Wd	We	Max Deviation
Panel 1	18.20	18.52	30.58	21.50	20.00	10.44	4.11
Panel 2	26.36	15.88	33.84	18.62	17.56	8.78	4.19
Panel 3	29.18	17.30	38.06	15.98	17.06	10.92	5.53
Panel 4	23.46	12.42	27.78	16.74	17.98	10.10	3.21
Panel 5	19.10	21.16	33.22	19.14	20.32	12.64	11.34
Panel 6	20.66	12.86	23.80	17.90	22.72	13.54	8.99
Panel 7	22.30	19.04	38.74	21.58	20.30	11.94	2.42
Panel 8	26.26	22.34	42.30	21.24	17.46	10.56	5.92
Panel 9	22.96	15.54	32.34	14.30	16.58	9.82	9.48
Panel 10	19.08	18.96	33.52	22.92	19.86	11.80	7.17
Panel 11	18.64	19.34	31.50	30.10	24.80	11.14	1.45
Panel 12	27.12	16.12	35.24	16.42	14.92	8.00	9.11
Panel 13	18.96	18.18	30.82	25.86	25.02	10.48	5.81
Panel 14	19.74	19.32	30.54	23.26	29.12	15.70	4.29
Panel 15	19.16	15.90	29.36	19.26	17.00	6.94	8.21
Panel 16	24.74	16.84	36.18	20.72	19.34	14.44	3.48
Average	22.25	17.48	32.99	20.35	20.00	11.08	

Table A.2: Wave-scan characteristics of white paint panels used in visual evaluation

Panel ID	Du	Wa	Wb	Wc	Wd	We	Max Deviation
Panel 1	8.22	17.76	43.04	22.76	22.82	10.90	3.77
Panel 2	9.88	12.26	38.58	28.44	25.76	10.98	1.99
Panel 3	33.12	47.94	55.54	36.92	28.56	16.96	21.25
Panel 4	5.12	6.06	18.20	14.34	22.10	8.84	12.22
Panel 6	14.76	30.86	60.56	37.46	29.76	16.64	12.58
Panel 7	8.64	14.18	39.92	22.10	22.32	11.34	4.10
Panel 8	8.90	13.94	42.32	31.12	27.70	13.82	4.34
Panel 9	9.90	13.88	42.32	37.86	30.52	14.70	5.96
Panel 13	8.42	13.62	40.12	22.68	20.70	8.56	4.66
Panel 14	11.64	14.20	41.10	31.48	27.64	14.82	4.94
Average	11.87	18.28	39.56	26.54	24.56	11.65	

Table A.3: Wave-scan characteristics of blue paint panels used for visual evaluation.

Panel ID	Du	Wa	Wb	Wc	Wd	We	Max Deviation
Panel 1	8.36	22.08	47.90	28.72	25.94	14.56	2.93
Panel 2	21.42	37.44	52.52	26.08	19.58	12.40	14.05
Panel 3	9.18	16.82	41.78	30.36	29.42	14.42	3.84
Panel 4	19.20	35.78	50.54	25.18	20.86	10.82	7.44
Panel 5	8.06	14.40	30.94	31.00	29.38	14.16	8.99
Panel 6	13.80	28.34	56.74	27.42	23.70	16.28	4.95
Panel 7	11.20	22.46	47.66	23.86	23.62	14.68	2.69
Panel 8	9.12	19.66	41.18	33.00	30.56	11.44	4.98
Panel 9	10.46	20.50	40.92	42.24	36.24	13.92	10.66
Panel 10	17.70	31.54	49.90	24.14	20.14	12.30	8.15
Panel 11	9.60	20.38	44.98	32.56	30.44	12.04	4.70
Panel 12	9.10	20.18	41.48	40.34	36.60	14.54	12.48
Panel 13	9.86	22.40	48.80	27.90	25.08	9.60	3.83
Panel 14	10.88	22.80	47.92	25.34	24.72	17.68	2.95
Average	12.00	23.91	45.95	29.87	26.88	13.49	

Appendix B: Wilcoxon rank sum test on the number of silver panelists

Appendix B: Wilcoxon rank sum test

	Medianrank, n= 60	Assigned Rank
Panel 1	9	16.5
Panel 3	6	5
Panel 4	5	1
Panel 5	7	5
Panel 6	10	21.5
Panel 8	11	26.5
Panel 10	8	13.5
Panel 11	6.5	7.5
Panel 12	10	21.5
Panel 13	9.5	18
Panel 14	12	30
Panel 15	7	10
Panel 16	11.5	29
Panel 17	13	31.5
Panel 18	6	5
Panel 19	10	21.5
	Sum of Ranks (T)	**263**

	Median rank, n=30	Assigned Rank
Panel 1	9	16.5
Panel 3	6	6
Panel 4	6.5	5
Panel 5	7	10
Panel 6	10	21.5
Panel 8	11	26.5
Panel 10	8	13.5
Panel 11	5.5	2.5
Panel 12	10	21.5
Panel 13	8.5	15
Panel 14	13	31.5
Panel 15	7.5	12
Panel 16	11	26.5
Panel 17	11	26.5
Panel 18	5.5	2.5
Panel 19	10	21.5
	Sum of Ranks	**258.5**

Mean $\mu_T = n_1 (n_1 + n_2 + 1)/2$

Standard Deviation (S.D.) = $\sqrt{\frac{1}{12} n_1 \cdot n_2 (n_1 + n_2 + 1)}$ where

n_1 = number of observations in Sample size 60
n_2 = number of observations in Sample size 30

Mean $\mu_T = n_1 (n_1 + n_2 + 1)/2 = \left(16 \cdot (16 + 16 + 1) / 2\right) = 264$

Standard Deviation (S.D.) = $\sqrt{\frac{1}{12} n_1 \cdot n_2 (n_1 + n_2 + 1)} = \sqrt{\frac{1}{12} \cdot 16 \cdot 16 (16 + 16 + 1)} = 26.5$

$$z = \frac{T - \mu_T}{\sigma_T} = \frac{263 - 258.5}{26.5} = 0.17$$

Appendix C: Summary of the visual evaluation results

Table C.1: Summary of data for regression analysis of silver paint panel

Panel #	Median	Du	Wa	Wb	Wc	Wd	We	LC	WL
Panel 1	9.00	18.20	18.52	30.58	21.50	20.00	10.44	0.21	-0.04
Panel 2	6.00	26.36	15.88	33.84	18.62	17.56	8.78	0.32	-0.03
Panel 3	6.50	29.18	17.30	38.06	15.98	17.06	10.92	0.38	0.03
Panel 4	7.00	23.46	12.42	27.78	16.74	17.98	10.10	0.21	0.04
Panel 5	10.00	19.10	21.16	33.22	19.14	20.32	12.64	0.24	0.03
Panel 6	11.00	20.66	12.86	23.80	17.90	22.72	13.54	0.02	0.12
Panel 7	8.00	22.30	19.04	38.74	21.58	20.30	11.94	0.31	-0.03
Panel 8	5.50	26.26	22.34	42.30	21.24	17.46	10.56	0.42	-0.10
Panel 9	10.00	22.96	15.54	32.34	14.30	16.58	9.82	0.32	0.07
Panel 10	8.50	19.08	18.96	33.52	22.92	19.86	11.80	0.26	-0.07
Panel 11	13.00	18.64	19.34	31.50	30.10	24.80	11.14	0.12	-0.10
Panel 12	7.50	27.12	16.12	35.24	16.42	14.92	8.00	0.41	-0.05
Panel 13	11.00	18.96	18.18	30.82	25.86	25.02	10.48	0.10	-0.02
Panel 14	11.00	19.74	19.32	30.54	23.26	29.12	15.70	0.02	0.11
Panel 15	5.50	19.16	15.90	29.36	19.26	17.00	6.94	0.27	-0.06
Panel 16	10.00	24.74	16.84	36.18	20.72	19.34	14.44	0.30	-0.03

Table C.2: Summary of data for regression analysis of white paint panel.

Panel #	Median	Du	Wa	Wb	Wc	Wd	We	LC	WL
Panel 1	8.50	8.22	17.76	43.04	22.76	22.82	10.90	0.31	0.00
Panel 2	4.00	9.88	12.26	38.58	28.44	25.76	10.98	0.20	-0.05
Panel 3	10.00	33.12	47.94	55.54	36.92	28.56	16.96	0.32	-0.13
Panel 4	3.00	5.12	6.06	18.20	14.34	22.10	8.84	-0.10	0.21
Panel 6	4.00	14.76	30.86	60.56	37.46	29.76	16.64	0.34	-0.11
Panel 7	4.50	8.64	14.18	39.92	22.10	22.32	11.34	0.28	0.00
Panel 8	6.00	8.90	13.94	42.32	31.12	27.70	13.82	0.21	-0.06
Panel 9	7.00	9.90	13.88	42.32	37.86	30.52	14.70	0.16	-0.11
Panel 13	5.00	8.42	13.62	40.12	22.68	20.70	8.56	0.32	-0.05
Panel 14	6.00	11.64	14.20	41.10	31.48	27.64	14.82	0.20	-0.06

Table C.3: Summary of data for regression analysis of blue paint panels

Panel #	Median	du	Wa	Wb	Wc	Wd	We	LC	WL
Panel 1	8.00	8.36	22.08	47.90	28.72	25.94	14.56	0.30	-0.05
Panel 2	5.50	21.42	37.44	52.52	26.08	19.58	12.40	0.46	-0.14
Panel 3	8.00	9.18	16.82	41.78	30.36	29.42	14.42	0.17	-0.02
Panel 4	10.00	19.20	35.78	50.54	25.18	20.86	10.82	0.42	-0.09
Panel 5	7.00	8.06	14.40	30.94	31.00	29.38	14.16	0.03	-0.03
Panel 6	8.00	13.80	28.34	56.74	27.42	23.70	16.28	0.41	-0.07
Panel 7	5.50	11.20	22.46	47.66	23.86	23.62	14.68	0.34	-0.01
Panel 8	5.00	9.12	19.66	41.18	33.00	30.56	11.44	0.15	-0.04
Panel 9	2.50	10.46	20.50	40.92	42.24	36.24	13.92	0.06	-0.08
Panel 10	6.00	17.70	31.54	49.90	24.14	20.14	12.30	0.42	-0.09
Panel 11	9.00	9.60	20.38	44.98	32.56	30.44	12.04	0.19	-0.03
Panel 12	9.00	9.10	20.18	41.48	40.34	36.60	14.54	0.06	-0.05
Panel 13	9.00	9.86	22.40	48.80	27.90	25.08	9.60	0.32	-0.05
Panel 14	6.00	10.88	22.80	47.92	25.34	24.72	17.68	0.32	-0.01

Appendix D: Distribution identification

Table D.1 : Individual distribution identification–silver paint panels

Distribution	Anderson darling co-efficient	P – value
Normal	**0.307**	**0.524**
Box-Cox Transformation	0.324	0.494
Lognormal	0.368	0.386
3-Parameter Lognormal	0.354	*
Exponential	4.122	<0.003
2-Parameter Exponential	0.957	0.066
Weibull	0.313	>0.250
3-Parameter Weibull	0.471	0.253
Smallest Extreme Value	0.370	>0.250
Largest Extreme Value	0.417	>0.250
Gamma	0.370	>0.250
3-Parameter Gamma	0.376	*
Logistic	0.353	>0.250
Loglogistic	0.398	>0.250
3-Parameter Loglogistic	0.357	*

Table D.2: Individual distribution identification–white paint panels

Distribution	Anderson darling co-efficient	P – value
Normal	**0.298**	**0.519**
Box-Cox Transformation	0.185	0.928
Lognormal	0.185	0.289
3-Parameter Lognormal	0.169	*
Exponential	1.997	0.007
2-Parameter Exponential	0.727	0.107
Weibull	0.275	>0.250
3-Parameter Weibull	0.208	>0.500
Smallest Extreme Value	0.523	0.175
Largest Extreme Value	0.189	>0.250
Gamma	0.206	>0.250
3-Parameter Gamma	0.255	*
Logistic	0.281	>0.250
Loglogistic	0.182	>0.250
3-Parameter Loglogistic	0.175	*

Table D.3 : Individual distribution identification–blue paint panels

Distribution	Anderson darling co-efficient	P – value
Normal	**0.377**	**0.359**
Box-Cox Transformation	0.354	0.411
Lognormal	0.699	0.052
3-Parameter Lognormal	0.397	*
Exponential	3.349	<0.003
2-Parameter Exponential	2.485	<0.010
Weibull	0.406	>0.250
3-Parameter Weibull	0.354	0.349
Smallest Extreme Value	0.354	>0.250
Largest Extreme Value	0.623	0.092
Gamma	0.556	0.171
3-Parameter Gamma	0.414	*
Logistic	0.397	>0.250
Loglogistic	0.513	0.145
3-Parameter Loglogistic	0.397	*

Appendix E: Paired t- test of Wave-scan readings before and after visual evaluation

Table E.1: Paired t- test of Wave-scan readings before and after visual evaluation of silver paint panels

Silver - Du	Before	After	Difference
N	16	16	16
Mean	22.245	22.469	-0.22
Std. Deviation	3.573	3.143	4.45
SE Mean	0.893	0.786	1.11
95% CI	(-2.60,2.15)		
T-value	-0.2		
P-value	0.843		

Silver Wc	Before	After	Difference
N	16	16	16
Mean	20.35	20.83	-0.49
Std. Deviation	4	4.34	6.44
SE Mean	1	1	1.61
95% CI	(-3.92,2.94)		
T-value	-0.3		
P-value	0.766		

Silver Wa	Before	After	Difference
N	16	16	16
Mean	17.483	16.906	0.576
Std. Deviation	2.687	3.256	3.617
SE Mean	0.672	0.814	0.904
95% CI	(-1.351,2.504)		
T-value	0.64		
P-value	0.534		

Silver Wd	Before	After	Difference
N	16	16	16
Mean	20.003	20.459	-0.46
Std. Deviation	3.751	3.902	4.02
SE Mean	0.938	0.975	1
95% CI	(-2.60,1.68)		
T-value	-0.45		
P-value	0.656		

Silver Wb	Before	After	Difference
N	16	16	16
Mean	32.99	32.51	0.48
Std. Deviation	6.36	4.38	6.36
SE Mean	1.13	1.09	1.59
95% CI	(-2.91,3.87)		
T-value	0.3		
P-value	0.768		

Silver We	Before	After	Difference
N	16	16	16
Mean	11.078	10.097	0.98
Std. Deviation	2.279	1.927	2.384
SE Mean	0.57	0.482	0.596
95% CI	(-0.290,2.250)		
T-value	1.64		
P-value	0.121		

Table E.2: Paired t- test of Wave-scan readings before and after visual evaluation of white paint panels

White - Du	Before	After	Difference
N	10	10	10
Mean	11.86	12.45	-0.59
Std. Deviation	7.87	7.22	11.08
SE Mean	2.49	2.28	3.5
95% CI	(-8.52,7.34)		
T-value	-0.17		
P-value	0.87		

White- Wc	Before	After	Difference
N	10	10	10
Mean	28.52	29.22	-0.7
Std. Deviation	7.91	8.05	13.05
SE Mean	2.5	2.54	4.13
95% CI	(-10.03,8.63)		
T-value	-0.17		
P-value	0.869		

White - Wa	Before	After	Difference
N	10	10	10
Mean	18.47	18.15	0.32
Std. Deviation	12.1	12.36	17.1
SE Mean	3.83	3.91	5.41
95% CI	(-11.91,12.55)		
T-value	0.06		
P-value	0.954		

White - Wd	Before	After	Difference
N	10	10	10
Mean	25.79	26.12	-0.33
Std. Deviation	3.55	4.5	7.08
SE Mean	1.12	1.42	2.24
95% CI	(-5.40,4.74)		
T-value	-0.15		
P-value	0.887		

White-Wb	Before	After	Difference
N	10	10	10
Mean	42.17	41.91	0.26
Std. Deviation	11.13	11.47	15.03
SE Mean	3.52	3.63	4.75
95% CI	(-10.42,11.02)		
T-value	0.06		
P-value	0.957		

White - We	Before	After	Difference
N	10	10	10
Mean	12.76	12.33	0.42
Std. Deviation	3.05	3.21	5.28
SE Mean	0.96	1.01	1.67
95% CI	(-3.35,4.20)		
T-value	0.25		
P-value	0.806		

Table E.3: Paired t- test of Wave-scan readings before and after visual evaluation of blue paint panels

Blue -Du	Before	After	Difference
N	14	14	14
Mean	12	12.56	-0.56
Std. Deviation	4.34	4.13	6.61
SE Mean	1.16	1.1	1.77
95% CI	(-4.37,3.25)		
T-value	-0.32		
P-value	0.756		

Blue - Wc	Before	After	Difference
N	14	14	14
Mean	29.87	29.96	-0.1
Std. Deviation	5.67	6	7.66
SE Mean	1.52	1.6	2.05
95% CI	(-4.52,4.33)		
T-value	-0.05		
P-value	0.963		

Blue - Wa	Before	After	Difference
N	14	14	14
Mean	23.91	22.42	1.49
Std. Deviation	6.84	7.11	10.57
SE Mean	1.83	1.9	2.83
95% CI	(-4.61,7.60)		
T-value	0.53		
P-value	0.606		

Blue - Wd	Before	After	Difference
N	14	14	14
Mean	26.88	26.88	0
Std. Deviation	5.45	5.12	8.03
SE Mean	1.46	1.37	2.15
95% CI	(-4.64,4.63)		
T-value	0		
P-value	0.998		

Blue - Wb	Before	After	Difference
N	14	14	14
Mean	45.95	44.21	1.73
Std. Deviation	6.36	6.18	7.77
SE Mean	1.7	1.65	2.08
95% CI	(-2.75,6.22)		
T-value	0.83		
P-value	0.419		

Blue - We	Before	After	Difference
N	14	14	14
Mean	13.489	14.133	-0.644
Std. Deviation	2.178	2.461	3.258
SE Mean	0.582	0.658	0.871
95% CI	(-2.525,1.237)		
T-value	-0.74		
P-value	0.472		

Appendix F: Backward, Forward and Subsetting Regression

Table F.1: Forward regression of measurements on silver paint panels

Stepwise Regression: Median versus Du, Wa, Wb, Wc, Wd, We, LC, WL (Silver)

Forward selection. Alpha-to-Enter: 0.5

Response is Median on 8 predictors, with N = 16

Step	1	2	3	4	5	6
Constant	-0.2511	3.3503	3.8196	5.3711	2.0273	-7.8681
Wd	0.45	0.41	0.30	0.03	-1.52	-0.74
T-Value	4.15	3.49	1.79	0.10	-2.38	-0.97
P-Value	0.001	0.004	0.099	0.920	0.039	0.359
Wb		-0.086	-0.114	-0.190	-0.092	-0.797
T-Value		-0.88	-1.12	-1.55	-0.87	-1.78
P-Value		0.394	0.284	0.148	0.404	0.109
We			0.25	0.43	0.32	0.48
T-Value			0.98	1.43	1.29	1.92
P-Value			0.347	0.180	0.226	0.087
Wc				0.21	1.82	2.03
T-Value				1.10	2.86	3.36
P-Value				0.295	0.017	0.008
WL					75	82
T-Value					2.61	3.03
P-Value					0.026	0.014
LC						47
T-Value						1.61
P-Value						0.142
S	1.57	1.58	1.59	1.57	1.27	1.18
R-Sq	55.14	57.67	60.79	64.68	79.02	83.71
R-Sq(adj)	51.94	51.16	50.99	51.84	68.53	72.86
Mallows Cp	8.0	8.9	9.5	9.7	5.3	5.3

Table F.2: Backward regression of measurements on silver paint panels

Stepwise Regression: Median versus du, Wa, Wb, Wc, Wd, We, LC, WL (Silver)

Backward elimination. Alpha-to-Remove: 0.01

Response is Median on 8 predictors, with N = 16

Step	1	2	3	4	5	6	7
Constant	-7.452	-7.212	-7.868	-11.374	-9.461	1.675	-0.6164
du	0.02						
T-Value	0.07						
P-Value	0.948						
Wa	0.14	0.12					
T-Value	0.38	0.54					
P-Value	0.713	0.605					
Wb	-0.87	-0.84	-0.80	-1.07	-0.69	-0.06	
T-Value	-1.46	-1.78	-1.78	-3.10	-2.04	-0.56	
P-Value	0.187	0.114	0.109	0.011	0.066	0.583	
Wc	2.06	2.05	2.03	1.68	1.48	0.45	0.47
T-Value	3.00	3.25	3.36	3.49	2.73	3.97	4.45
P-Value	0.020	0.012	0.008	0.006	0.019	0.002	0.001
Wd	-0.82	-0.82	-0.74				
T-Value	-0.95	-1.01	-0.97				
P-Value	0.376	0.343	0.359				
We	0.49	0.49	0.48	0.52			
T-Value	1.71	1.86	1.92	2.12			
P-Value	0.131	0.100	0.087	0.060			
LC	47	47	47	65	46		
T-Value	1.44	1.54	1.61	2.88	1.94		
P-Value	0.194	0.162	0.142	0.016	0.078		
WL	84.4	84.3	82.2	66.2	65.7	20.1	22.5
T-Value	2.77	2.96	3.03	3.10	2.68	2.61	3.64
P-Value	0.028	0.018	0.014	0.011	0.021	0.023	0.003
S	1.31	1.23	1.18	1.18	1.35	1.50	1.46
R-Sq	84.29	84.28	83.71	82.02	73.96	65.04	64.12
R-Sq(adj)	66.34	70.53	72.86	73.04	64.49	56.30	58.60
Mallows Cp	9.0	7.0	5.3	4.0	5.6	7.6	6.0

Table F.3: Forward regression of measurements on White paint panels

Stepwise Regression: Median versus du, Wa, Wb, Wc, Wd, We, LC, WL (white – final model)

Forward selection. Alpha-to-Enter: 0.75

Response is Median on 8 predictors, with N = 10

Step	1	2	3	4	5	6	7	8
Constant	3.6606	3.1909	4.8179	-0.2580	-7.5037	-6.3747	11.91	33.77
du	0.180	0.157	0.192	0.225	-0.923	-0.933	-1.32	-1.96
T-Value	2.41	1.82	1.69	1.96	-2.85	-2.56	-1.89	-1.68
P-Value	0.042	0.112	0.143	0.107	0.046	0.083	0.199	0.343
LC		3.4	7.6	25.9	90.2	90.8	75	31
T-Value		0.64	0.77	1.39	4.41	3.95	2.15	0.45
P-Value		0.542	0.470	0.223	0.012	0.029	0.165	0.732
Wb			-0.07	-0.36	-1.74	-1.75	-1.87	-1.86
T-Value			-0.52	-1.26	-4.23	-3.79	-3.47	-3.05
P-Value			0.622	0.262	0.013	0.032	0.074	0.202
Wd				0.50	2.21	2.10	1.4	2.3
T-Value				1.15	4.18	3.22	1.14	1.25
P-Value				0.303	0.014	0.049	0.371	0.430
Wa					1.09	1.09	1.37	1.93
T-Value					3.61	3.20	2.43	1.96
P-Value					0.023	0.049	0.136	0.300
We						0.22	0.68	1.12
T-Value						0.43	0.77	0.96
P-Value						0.698	0.523	0.513
WL							-31	-152
T-Value							-0.68	-0.89
P-Value							0.568	0.537
Wc								-1.7
T-Value								-0.74
P-Value								0.593
S	1.77	1.83	1.94	1.89	1.02	1.15	1.27	1.44
R-Sq	42.12	45.33	47.69	58.61	90.29	90.84	92.55	95.21
R-Sq(adj)	34.88	29.71	21.54	25.49	78.14	72.53	66.48	56.86
Mallows Cp	6.1	7.4	8.9	8.6	4.0	5.9	7.6	9.0

Table F.4: Backward regression of measurements on white paint panels

Stepwise Regression: Median versus du, Wa, Wb, Wc, Wd, We, LC, WL (White)

Backward elimination. Alpha-to-Remove: 0.01

Response is Median on 8 predictors, with N = 12

Step	1	2	3	4	5	6	7	8	9
Constant	-17.095	-18.245	-17.329	-7.985	-3.524	1.620	0.6986	4.2507	6.7500
du	-0.63	-0.59	-0.61	-0.79					
T-Value	-0.55	-0.89	-1.07	-1.57					
P-Value	0.622	0.423	0.333	0.167					
Wa	0.889	0.849	0.861	0.989	0.269	0.150	0.113	0.135	
T-Value	0.85	1.46	1.68	2.12	2.73	1.58	1.84	2.45	
P-Value	0.457	0.217	0.153	0.078	0.029	0.154	0.100	0.034	
Wb	-1.50	-1.51	-1.53	-1.58	-0.73	-0.06			
T-Value	-1.74	-2.02	-2.36	-2.54	-2.17	-0.52			
P-Value	0.180	0.114	0.065	0.044	0.067	0.614			
Wc	-0.55	-0.40	-0.38						
T-Value	-0.19	-0.68	-0.76						
P-Value	0.865	0.531	0.481						
Wd	2.94	2.83	2.76	2.11	1.04	0.19	0.16		
T-Value	1.07	1.96	2.33	2.67	2.34	0.92	0.84		
P-Value	0.363	0.121	0.067	0.037	0.052	0.382	0.423		
We	-0.08	-0.09							
T-Value	-0.09	-0.13							
P-Value	0.931	0.906							
LC	85	88	89	82	42				
T-Value	1.12	2.34	2.62	2.61	2.08				
P-Value	0.345	0.079	0.047	0.040	0.076				
WL	-9								
T-Value	-0.05								
P-Value	0.964								
S	2.17	1.88	1.68	1.62	1.78	2.12	2.03	2.00	2.42
R-Sq	78.08	78.06	77.97	75.42	65.32	43.96	42.03	37.48	-0.00
R-Sq(adj)	19.62	39.66	51.54	54.94	45.50	22.94	29.14	31.23	0.00
Mallows Cp	9.0	7.0	5.0	3.4	2.7	3.7	1.9	0.6	3.7

Table F.5: Forward regression of measurements on blue paint panels

Stepwise Regression: Median versus du, Wa, Wb, Wc, Wd, We, LC, WL (Blue – Final Model)

Forward selection. Alpha-to-Enter: 0.5

Response is Median on 8 predictors, with N = 14

Step	1	2	3	4	5	6	7	8
Constant	9.8318	11.9732	13.1909	0.6662	-15.3533	-7.1000	-5.948	-4.074
We	-0.21	-0.20	-0.29	-0.18	-0.26	-0.34	-0.40	-0.31
T-Value	-0.78	-0.75	-0.99	-0.59	-0.93	-1.14	-1.25	-0.95
P-Value	0.450	0.471	0.346	0.567	0.381	0.290	0.257	0.386
Wc		-0.07	-0.35	-3.36	-4.53	-4.31	-4.1	-4.5
T-Value		-0.71	-1.02	-1.47	-2.01	-1.88	-1.71	-1.86
P-Value		0.492	0.332	0.176	0.079	0.102	0.138	0.121
Wd			0.30	3.72	5.19	4.19	3.6	4.0
T-Value			0.84	1.44	2.01	1.47	1.18	1.32
P-Value			0.419	0.185	0.079	0.186	0.284	0.244
WL				-167	-219	-208	-170	-193
T-Value				-1.33	-1.81	-1.68	-1.24	-1.40
P-Value				0.216	0.108	0.136	0.263	0.220
Wb					0.21	0.79	1.05	0.85
T-Value					1.56	1.17	1.34	1.07
P-Value					0.156	0.281	0.229	0.335
LC						-49	-78	-73
T-Value						-0.87	-1.11	-1.06
P-Value						0.411	0.309	0.338
Wa							0.26	0.76
T-Value							0.74	1.31
P-Value							0.490	0.248
du								-0.73
T-Value								-1.07
P-Value								0.332
S	2.08	2.13	2.16	2.08	1.93	1.96	2.02	2.00
R-Sq	4.84	9.02	15.06	29.04	45.67	51.02	55.07	63.50
R-Sq(adj)	0.00	0.00	0.00	0.00	11.71	9.04	2.66	5.09
Mallows Cp	3.0	4.5	5.6	5.7	5.4	6.7	8.2	9.0

Table F.6: Backward regression of measurements on blue paint panels

Stepwise Regression: Median versus Du, Wa, Wb, Wc, Wd, We, LC, WL (Blue – Final Model)

Backward elimination. Alpha-to-Remove: 0.01

Response is Median on 8 predictors, with N = 14

Step	1	2	3	4	5	6	7	8	9
Constant	-4.074	-10.055	-13.083	-14.977	-11.148	-3.096	9.338	9.304	7.036
du	-0.73	-0.89	-0.96	-0.88					
T-Value	-1.07	-1.38	-1.54	-1.92					
P-Value	0.332	0.218	0.166	0.091					
Wa	0.76	0.80	0.75	0.66	0.20				
T-Value	1.31	1.38	1.35	2.03	0.80				
P-Value	0.248	0.216	0.218	0.076	0.442				
Wb	0.85	0.51							
T-Value	1.07	0.72							
P-Value	0.335	0.497							
Wc	-4.5	-5.0	-5.0	-5.1	-4.0	-3.7	-0.24	-0.08	
T-Value	-1.86	-2.17	-2.26	-2.52	-1.81	-1.72	-0.74	-0.74	
P-Value	0.121	0.073	0.058	0.036	0.105	0.116	0.477	0.471	
Wd	4.0	5.0	5.6	5.8	4.6	4.1	0.18		
T-Value	1.32	1.74	2.15	2.49	1.80	1.68	0.53		
P-Value	0.244	0.133	0.069	0.037	0.106	0.123	0.608		
We	-0.31								
T-Value	-0.95								
P-Value	0.386								
LC	-73	-47	-4						
T-Value	-1.06	-0.75	-0.21						
P-Value	0.338	0.481	0.841						
WL	-193	-237	-246	-254	-183	-188			
T-Value	-1.40	-1.84	-2.00	-2.31	-1.55	-1.63			
P-Value	0.220	0.115	0.086	0.050	0.156	0.135			
S	2	1.98	1.91	1.80	2.05	2.01	2.15	2.09	2.05
R-Sq	63.5	56.9	53.1	52.87	31.20	26.26	6.77	4.41	-0.00
R-Sq(adj)	5.09	6.64	13.01	23.41	0.62	4.13	0.00	0.00	0.00
Mallows Cp	9.0	7.9	6.4	4.5	5.4	4.1	4.8	3.1	1.7

Table F.7: Subset regression of measurements on silver, white and blue paint panels

Best Subsets Regression: Median versus du, Wa, Wd, Wb, Wc, We, LC, WL (Silver)

Response is Median
The following variables are included in all models: Wb Wc We LC WL

Vars	R-Sq	R-Sq(adj)	Mallows Cp	S	du	Wa	Wd
1	83.7	72.9	5.3	1.1803			X
1	82.3	70.5	5.9	1.2310		X	
2	84.3	70.5	7.0	1.2298		X	X
2	84.0	69.9	7.1	1.2422	X		X
3	84.3	66.3	9.0	1.3143	X	X	X

Best Subsets Regression: Median versus Wc, Wd, We, LC, WL, Du, Wa, Wb (White)

Response is Median
The following variables are included in all models: du Wa Wb

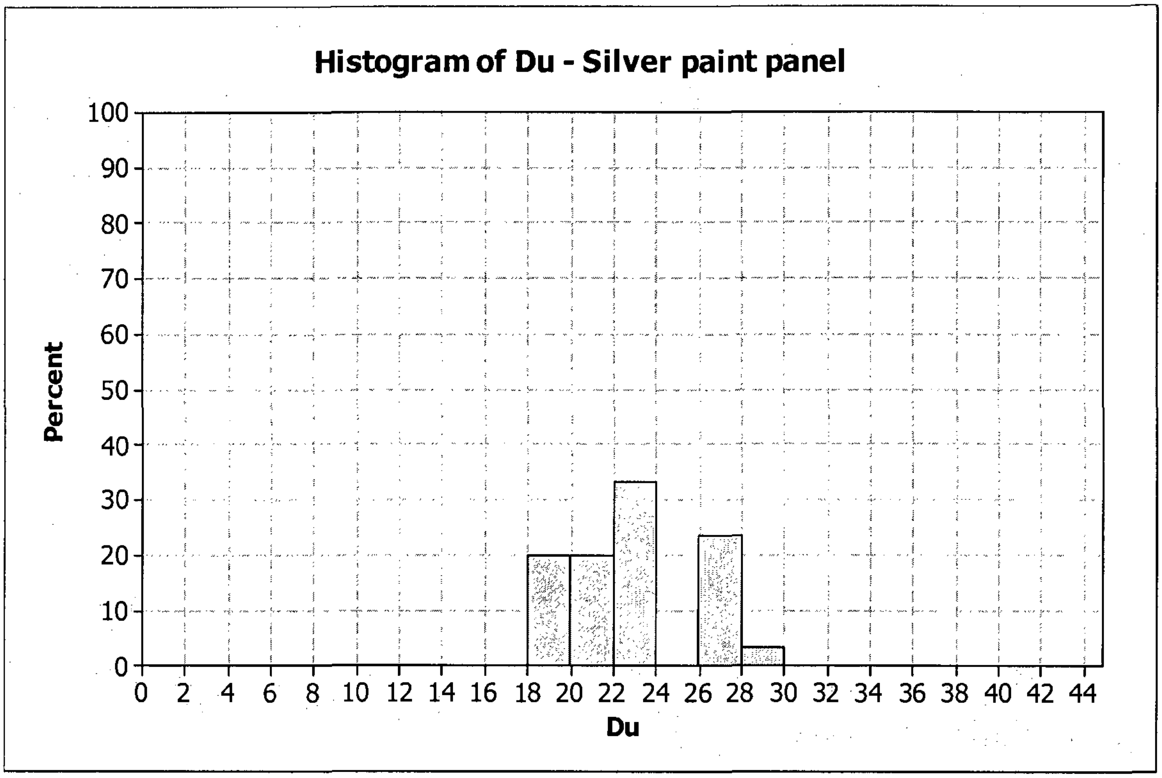
Vars	R-Sq	R-Sq(adj)	Mallows Cp	S	Wc	Wd	We	LC	WL
1	58.1	24.7	8.7	1.8995					X
1	47.9	6.2	10.9	2.1190				X	
2	90.3	78.1	4.0	1.0231		X		X	
2	72.8	38.8	7.7	1.7115	X			X	
3	90.8	72.5	5.9	1.1469		X	X	X	
3	90.4	71.1	6.0	1.1774		X		X	X
4	94.2	74.1	7.2	1.1139	X	X	X		X
4	92.6	66.5	7.6	1.2671		X	X	X	X
5	95.2	56.9	9.0	1.4374	X	X	X	X	X

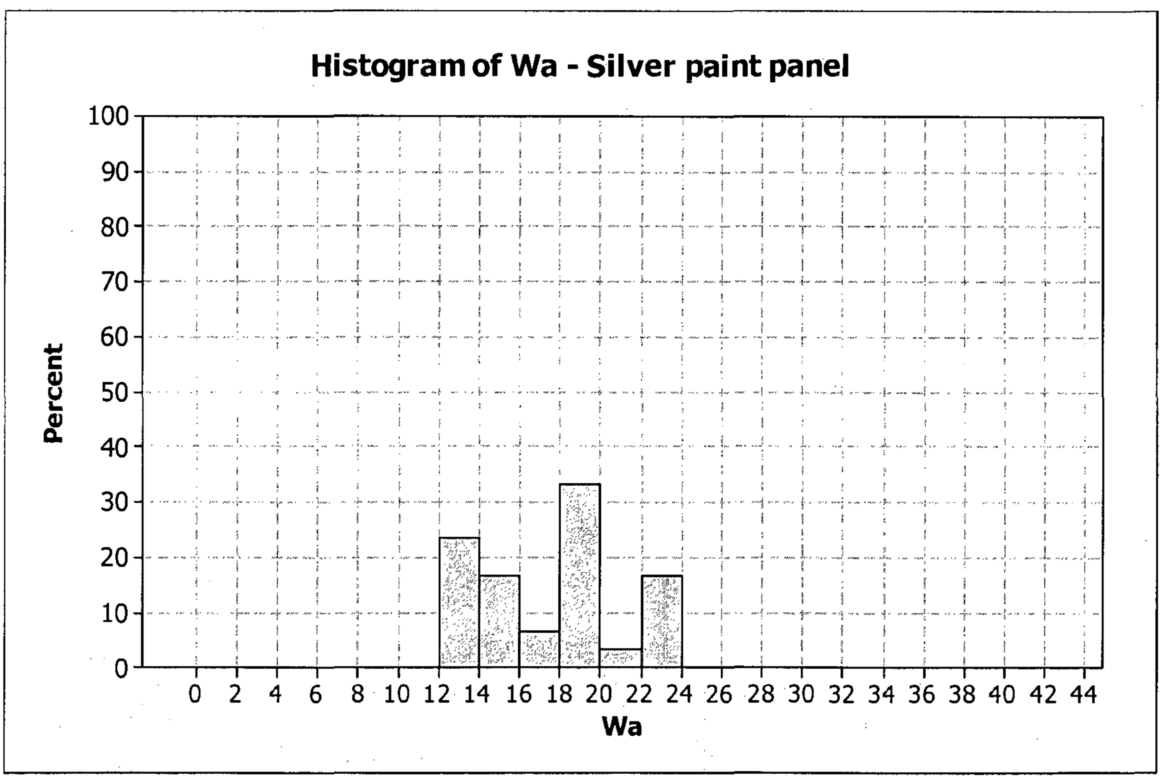
Best Subsets Regression: Median versus Du, Wa, Wb, We, LC, Wc, Wd, WL (Blue)

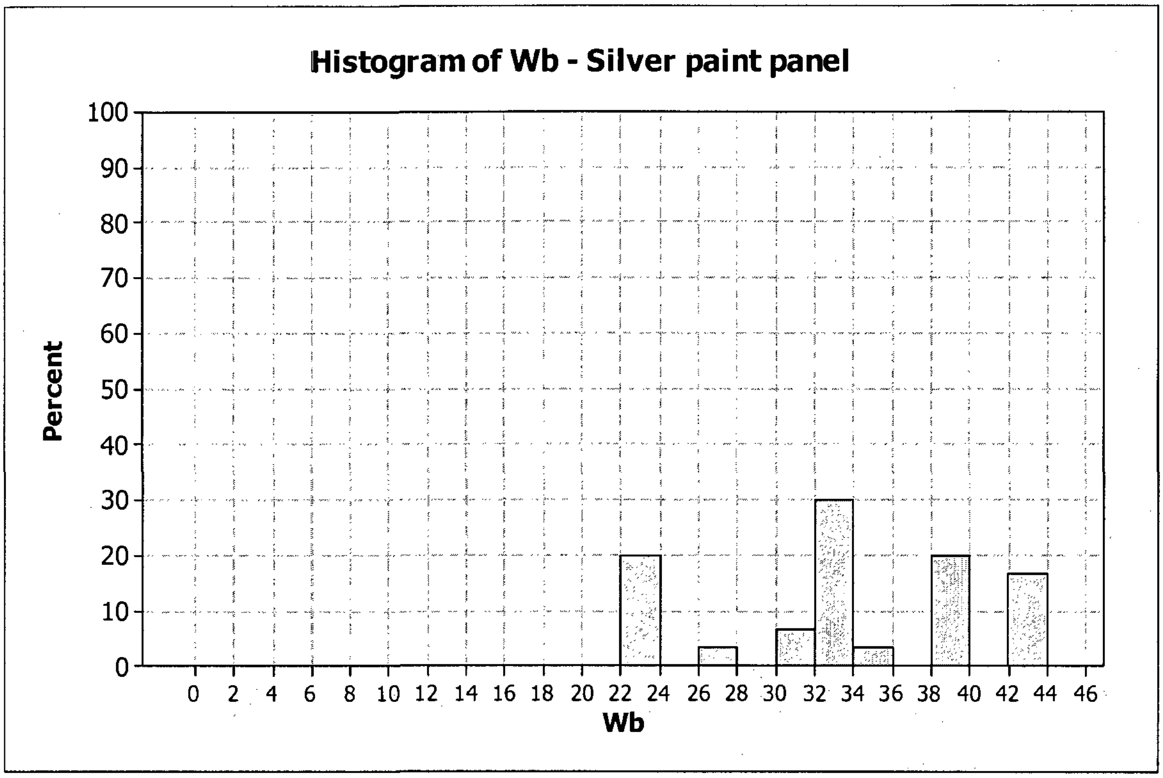
Response is Median
The following variables are included in all models: Wc Wd WL

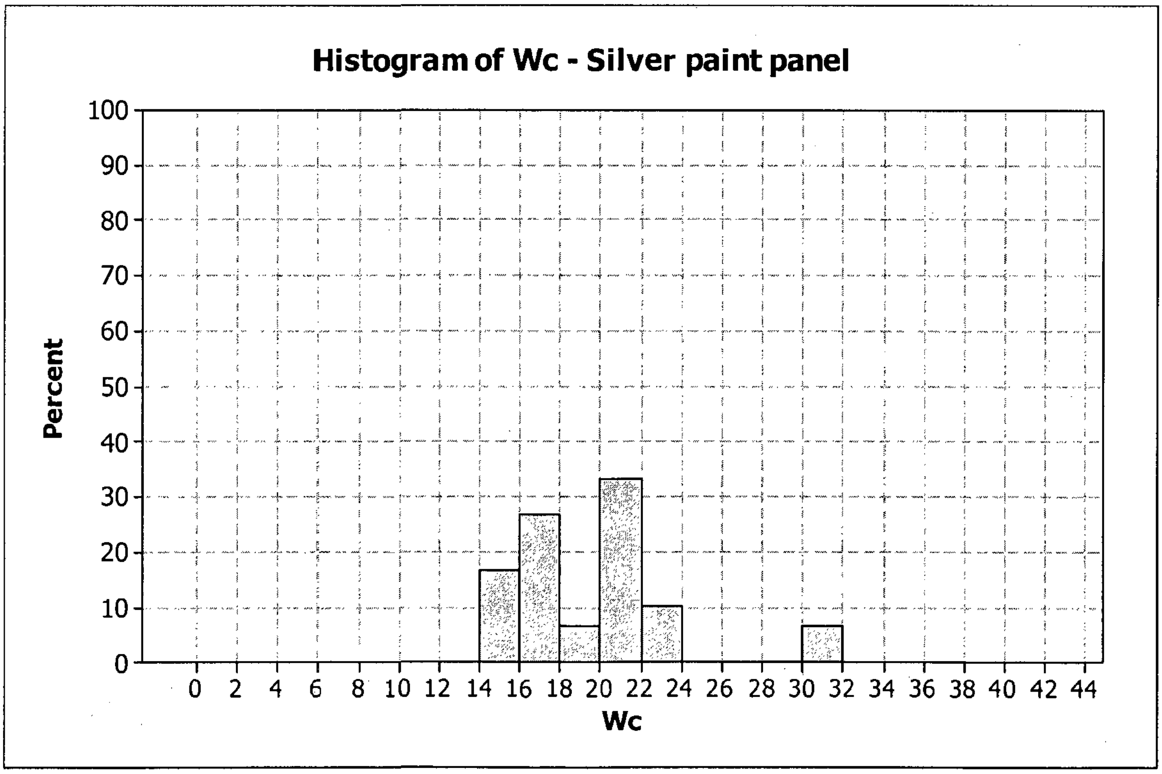
Vars	R-Sq	R-Sq(adj)	Mallows Cp	S	du	Wa	Wb	We	LC
1	39.8	13.1	4.2	1.9128			X		
1	37.1	9.2	4.6	1.9551					X
2	52.9	23.4	4.5	1.7958	X	X			
2	45.7	11.7	5.4	1.9279			X	X	
3	55.1	16.6	6.2	1.8738	X	X		X	
3	53.2	13.0	6.4	1.9138	X	X			X
4	56.9	6.6	7.9	1.9825	X	X	X		X
4	55.3	3.2	8.1	2.0189	X	X	X	X	
5	63.5	5.1	9.0	1.9989	X	X	X	X	X

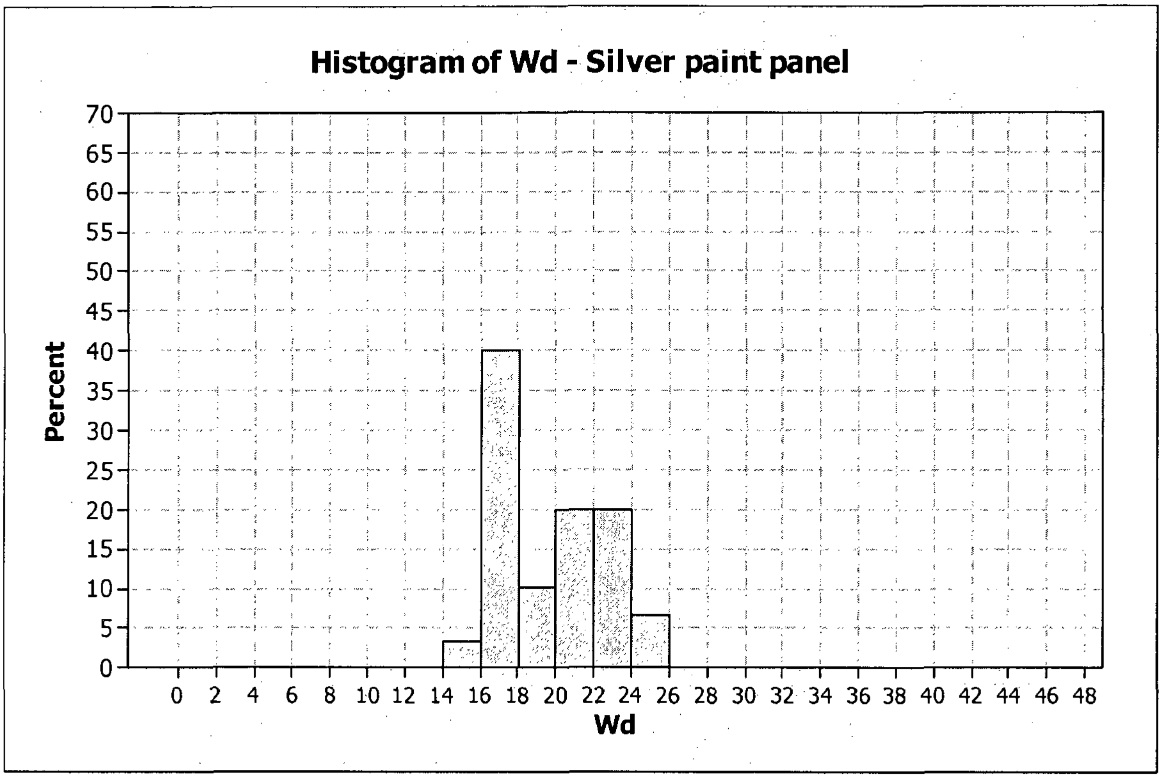
Appendix G: Frequency of occurrence of Wave-scan contrast values of panel deemed “minimum acceptable” by panelists, arranged by Wave-scan color and structure size

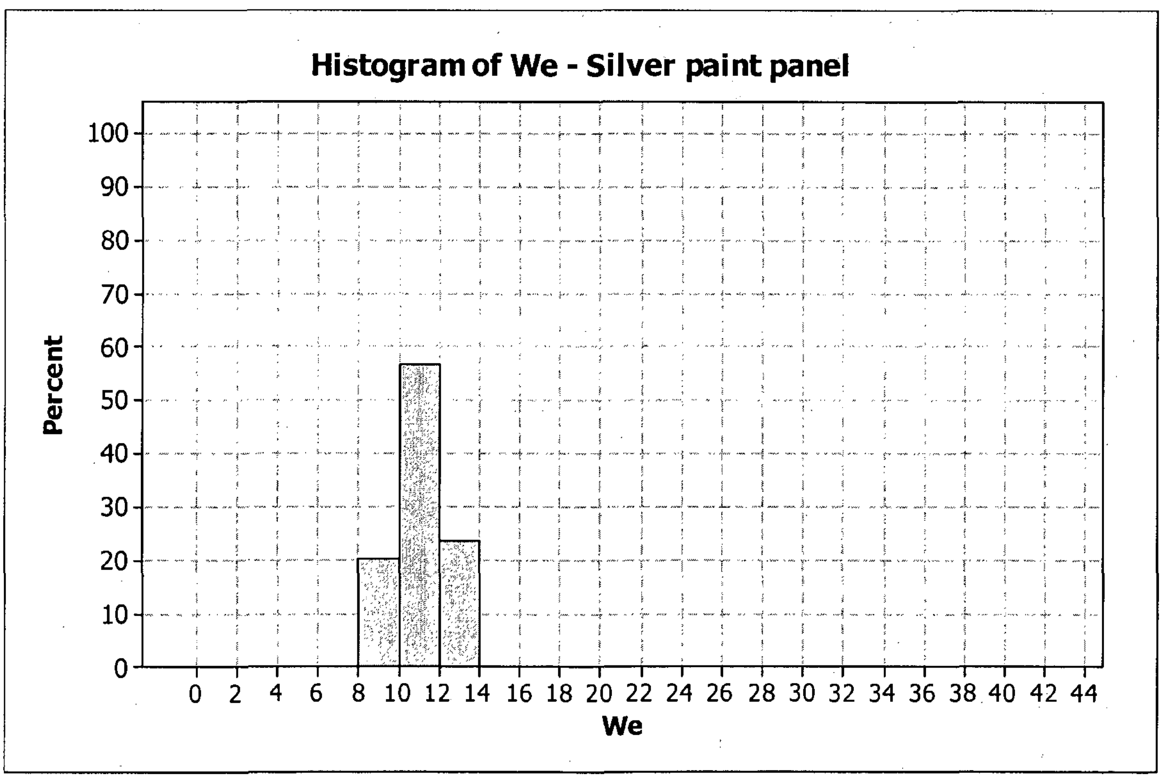

Histogram of Du - Silver paint panel
Percent
100
90
80
70
60
50
40
30
20
10
0
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44
Du

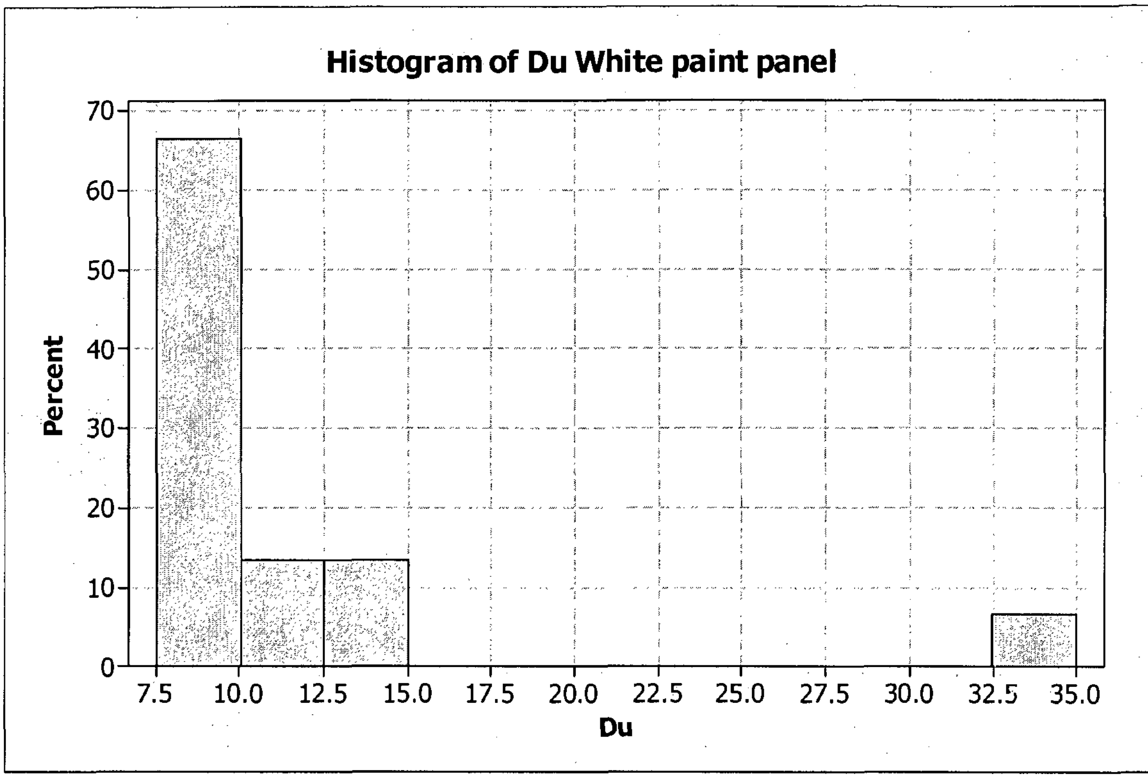

Histogram of Wa - Silver paint panel
Percent
100
90
80
70
60
50
40
30
20
10
0
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44
Wa

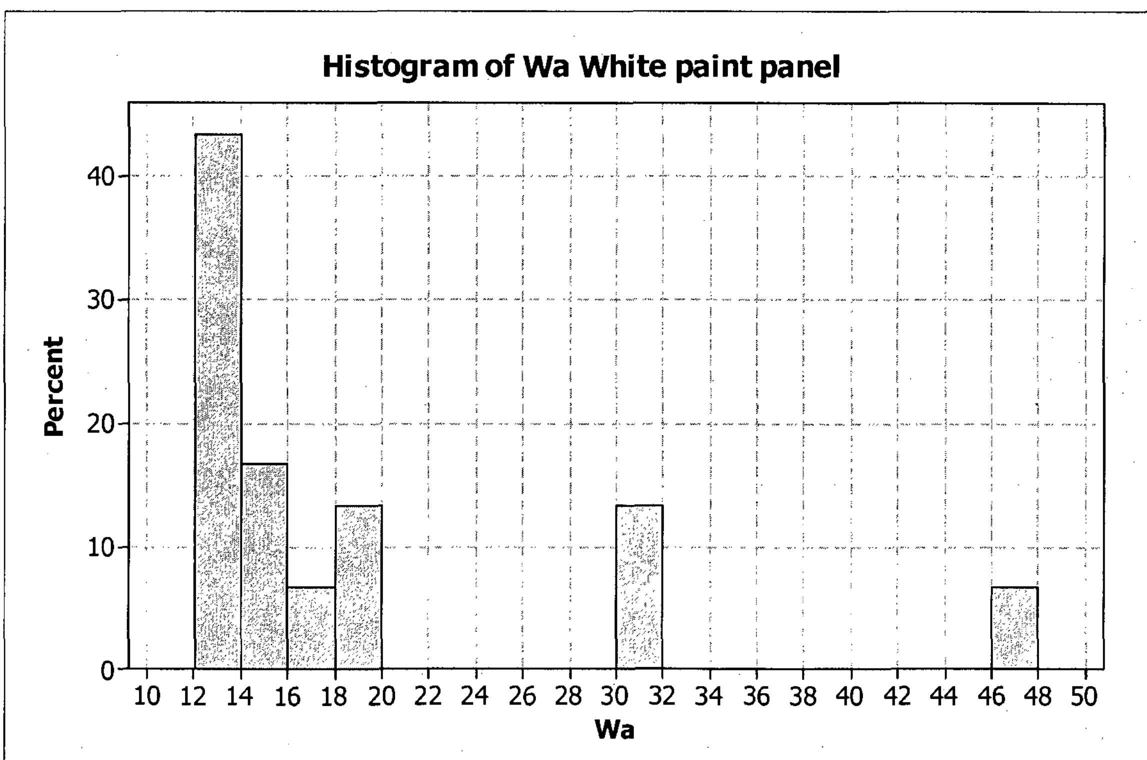

Histogram of Wb - Silver paint panel
Percent
Wb
100
90
80
70
60
50
40
30
20
10
0
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46

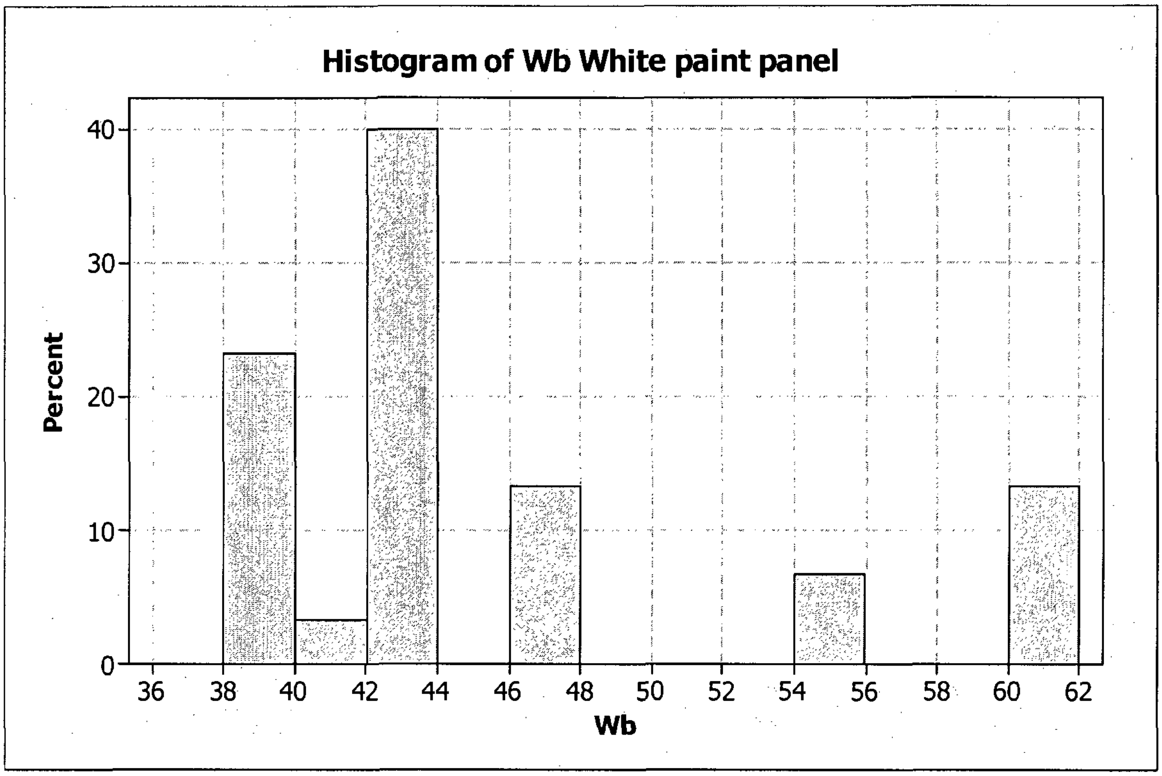

Histogram of Wc - Silver paint panel
Percent
Wc
100
90
80
70
60
50
40
30
20
10
0
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44

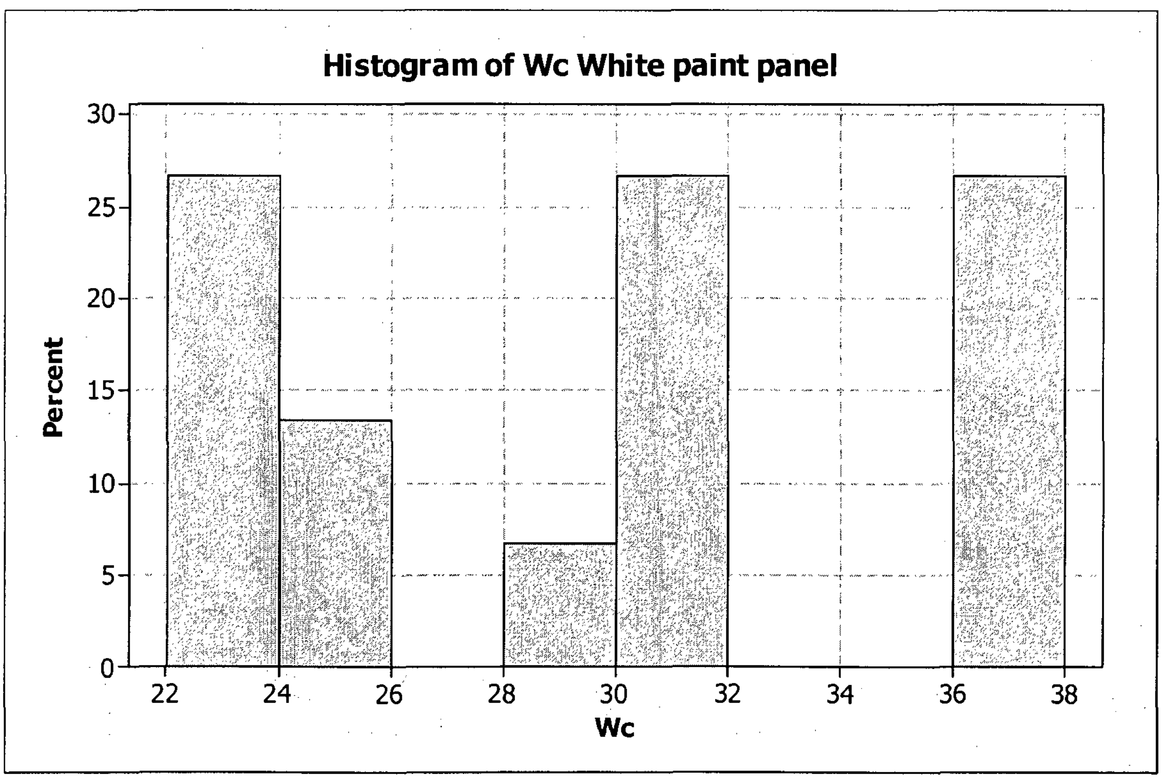

Histogram of Wd - Silver paint panel
Percent
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48
Wd

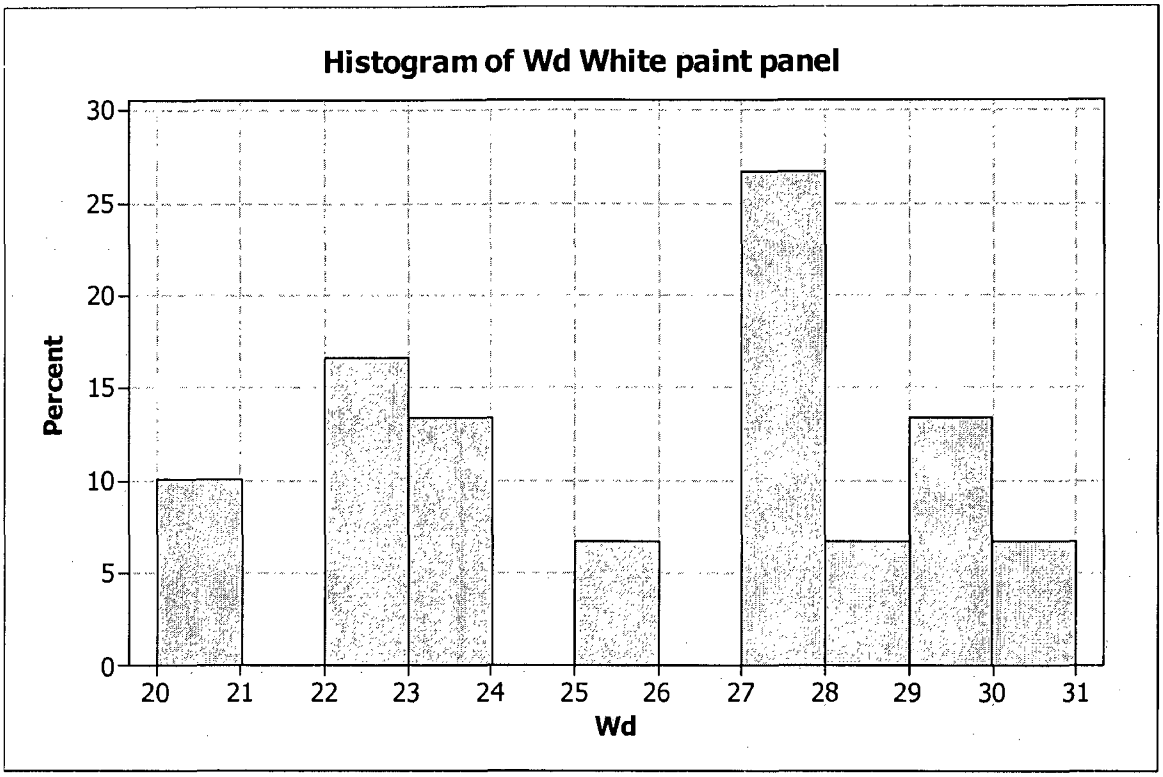

Histogram of We - Silver paint panel
Percent
100
90
80
70
60
50
40
30
20
10
0
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44
We

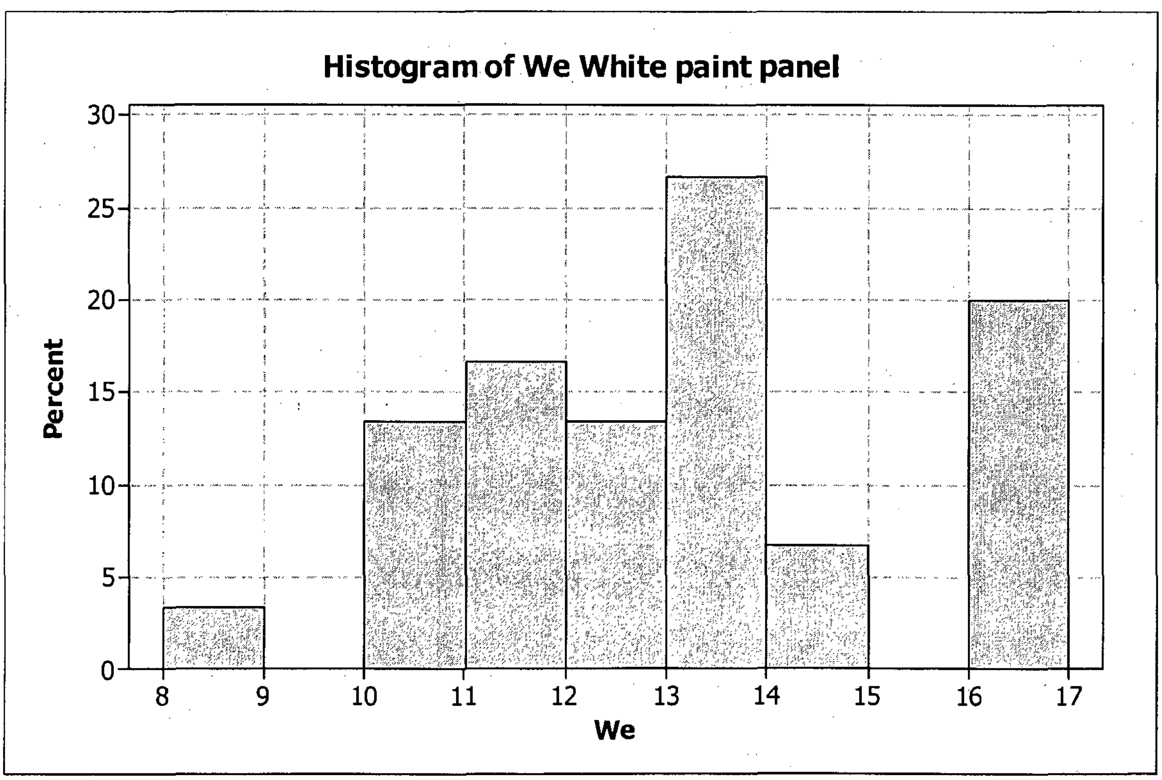

Histogram of Du White paint panel
Percent
70
60
50
40
30
20
10
0
7.5
10.0
12.5
15.0
17.5
20.0
22.5
25.0
27.5
30.0
32.5
35.0
Du

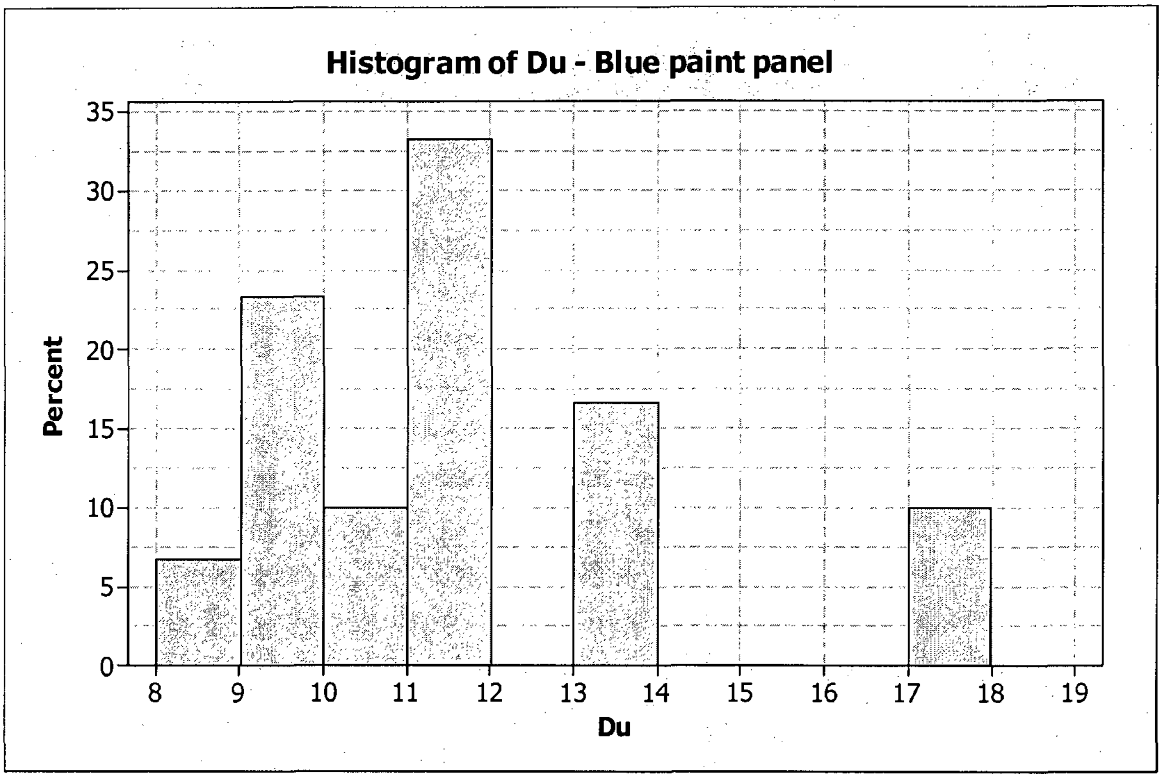

Histogram of Wa White paint panel
Percent
40
30
20
10
0
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
42
44
46
48
50
Wa

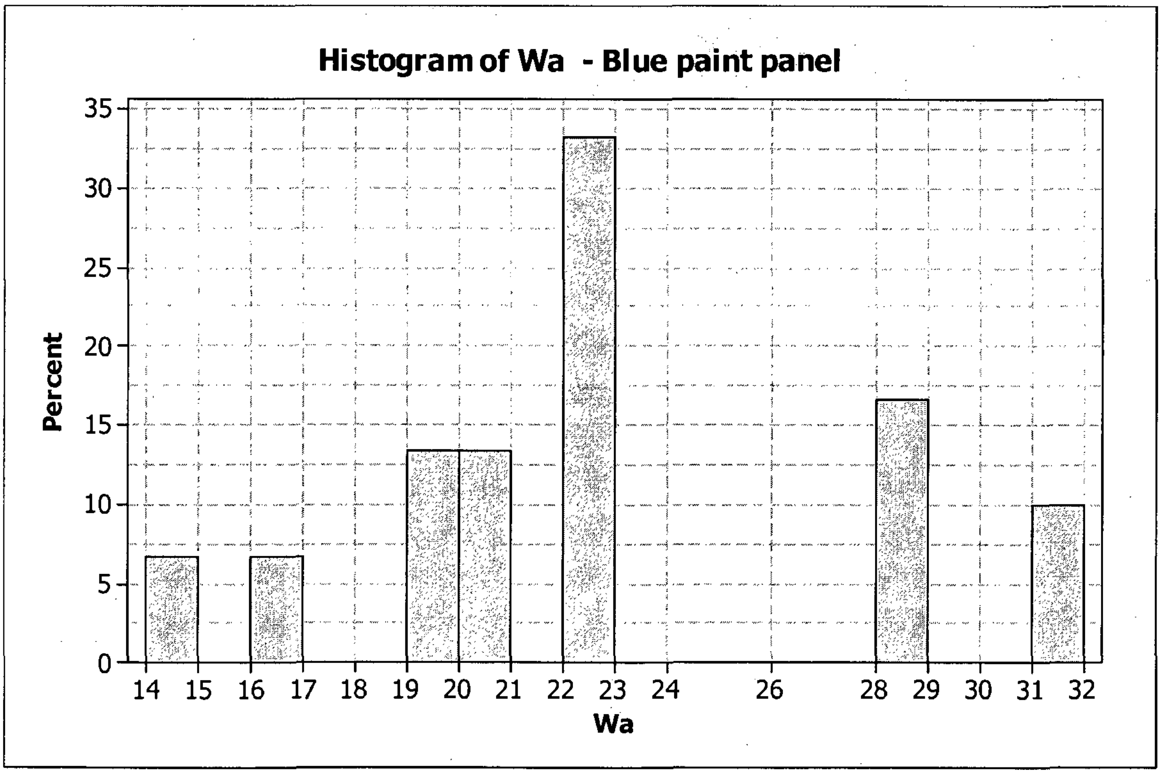

Histogram of Wb White paint panel
Percent
40
30
20
10
0
36
38
40
42
44
46
48
50
52
54
56
58
60
62
Wb

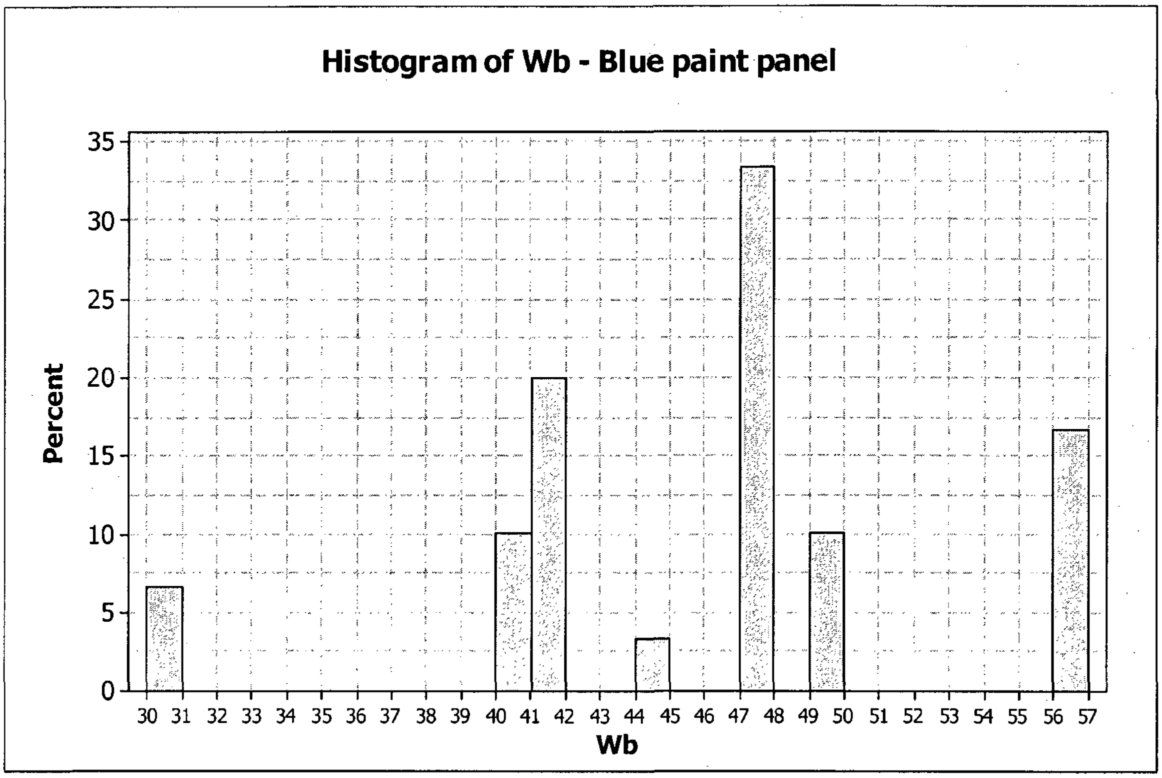

Histogram of Wc White paint panel
Percent
30
25
20
15
10
5
0
22
24
26
28
30
32
34
36
38
Wc

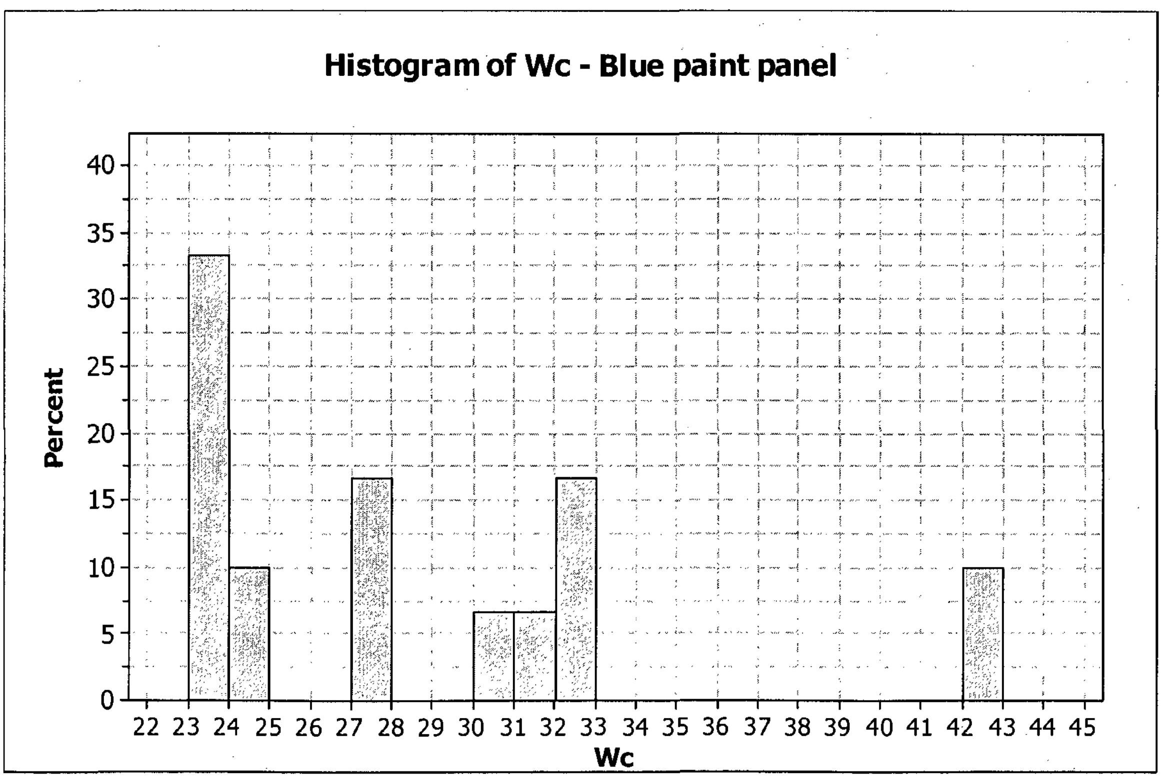

Histogram of Wd White paint panel
Percent
30
25
20
15
10
5
0
20 21 22 23 24 25 26 27 28 29 30 31
Wd

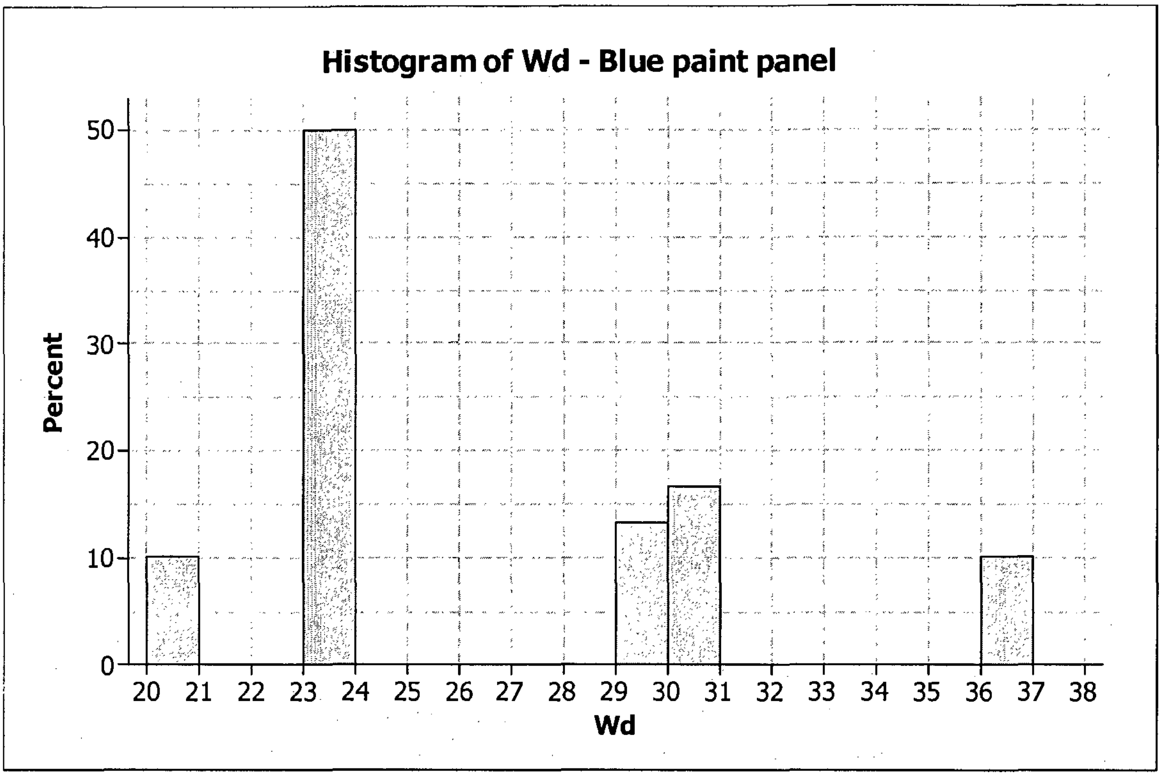

Histogram of We White paint panel
Percent
30
25
20
15
10
5
0
8 9 10 11 12 13 14 15 16 17
We

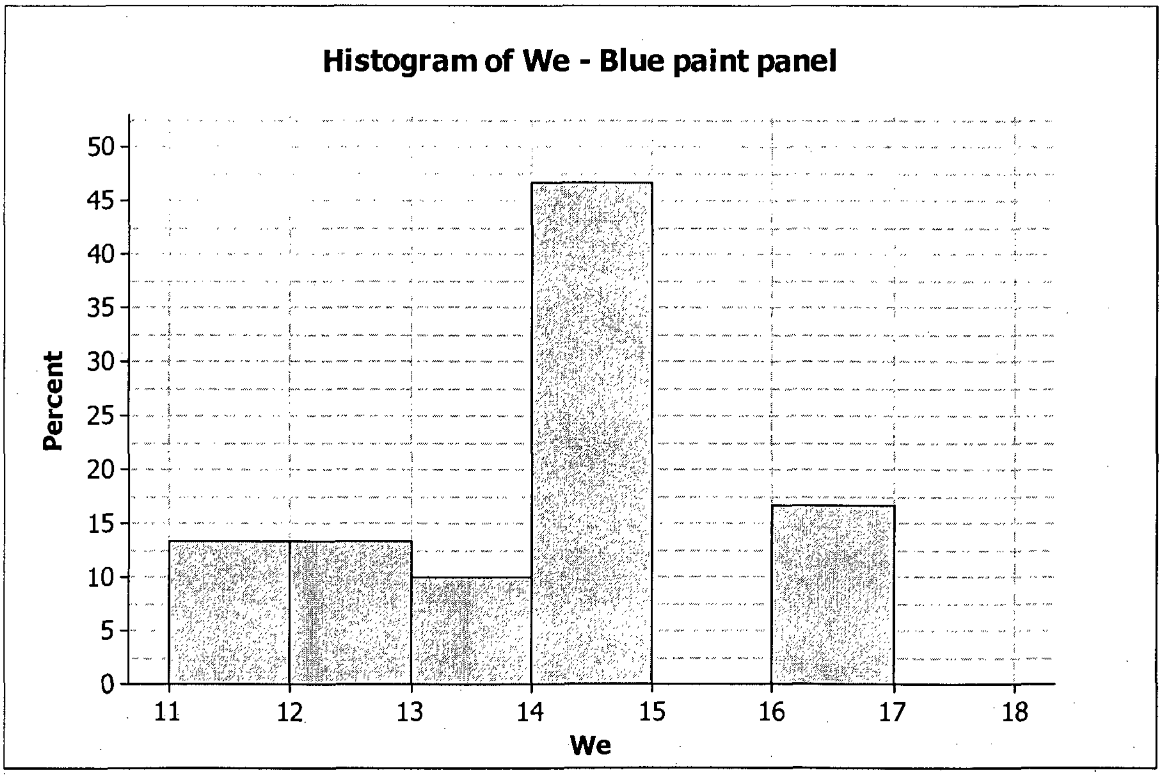

Histogram of Du - Blue paint panel
Percent
35
30
25
20
15
10
5
0
8 9 10 11 12 13 14 15 16 17 18 19
Du


Histogram of Wa - Blue paint panel
Percent
35
30
25
20
15
10
5
0
14 15 16 17 18 19 20 21 22 23 24 26 28 29 30 31 32
Wa


Histogram of Wb - Blue paint panel
Percent
0
5
10
15
20
25
30
35
30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57
Wb


Histogram of Wc - Blue paint panel
Percent
0
5
10
15
20
25
30
35
40
22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45
Wc


Histogram of Wd - Blue paint panel
Percent
0
10
20
30
40
50
20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38
Wd


Histogram of We - Blue paint panel
Percent
0
5
10
15
20
25
30
35
40
45
50
11 12 13 14 15 16 17 18
We

Appendix H: Regression using coded factors

Figure H.1: Regression analysis: Median versus coded factors (Wb, Wc, We, LC, WL) silver paint panel

```
The regression equation is
Median = 9.46 - 8.00 Wb + 9.70 Wc + 1.97 We + 12.8 LC + 7.16 WL

Predictor     Coef  SE Coef      T      P
Constant    9.4613   0.3821  24.76  0.000
Wb          -8.003    2.584  -3.10  0.011
Wc           9.703    2.782   3.49  0.006
We          1.9666   0.9286   2.12  0.060
LC          12.814    4.451   2.88  0.016
WL           7.158    2.312   3.10  0.011

S = 1.17638   R-Sq = 82.0%   R-Sq(adj) = 73.0%

Analysis of Variance
Source          DF      SS      MS     F      P
Regression       5  63.146  12.629  9.13  0.002
Residual Error  10  13.839   1.384
Total           15  76.984


Source  DF  Seq SS
Wb       1  13.775
Wc       1  21.010
We       1  14.982
LC       1   0.117
WL       1  13.261
```

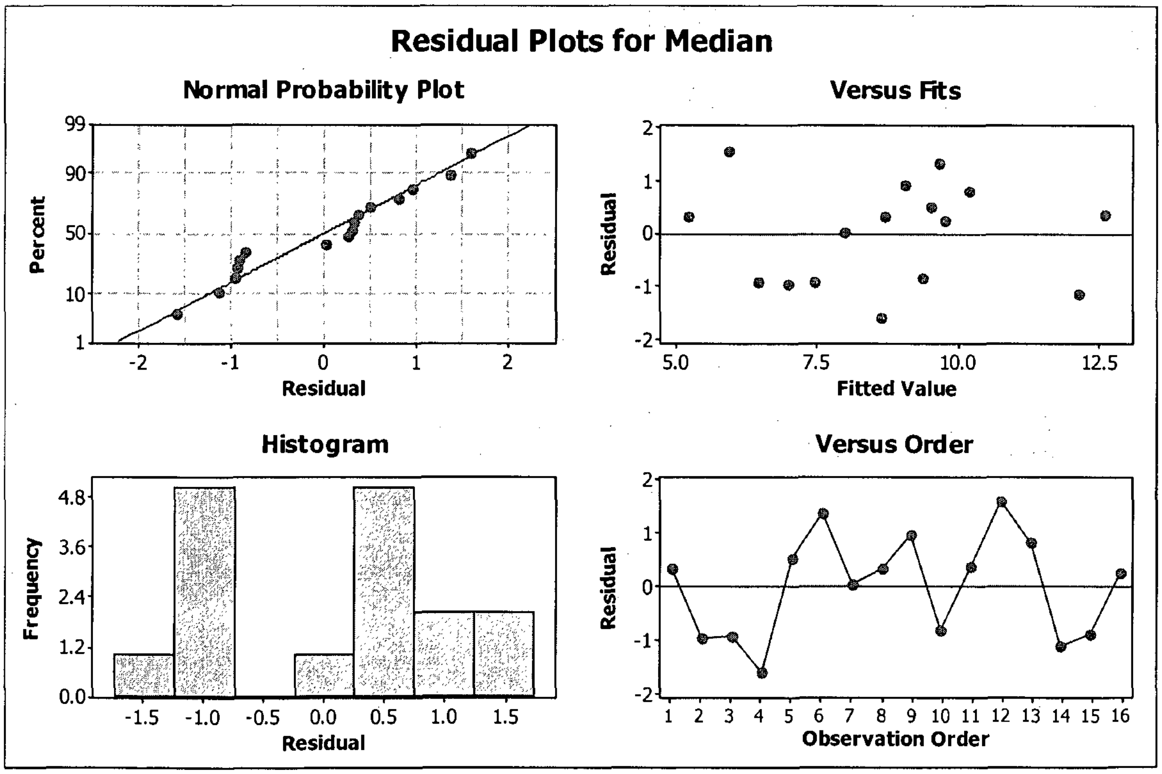


Figure H.2: Regression analysis: median versus coded factors (Du, Wa, Wb, Wd, LC) of white paint panel.

```
The regression equation is
Median = 3.68 - 12.9 Du + 22.9 Wa - 36.8 Wb + 10.9 Wd + 19.7 LC

Predictor      Coef  SE Coef       T      P
Constant     3.6801   0.9513    3.87  0.018
Du          -12.925    4.534   -2.85  0.046
Wa           22.893    6.338    3.61  0.023
Wb          -36.751    8.697   -4.23  0.013
Wd           10.857    2.599    4.18  0.014
LC           19.746    4.478    4.41  0.012

S = 1.02306    R-Sq = 90.3%    R-Sq(adj) = 78.1%
PRESS = 557.459    R-Sq(pred) = 0.00%

Analysis of Variance
Source          DF      SS      MS      F      P
Regression       5  38.913   7.783   7.44  0.037
Residual Error   4   4.187   1.047
Total            9  43.100

Source  DF  Seq SS
Du       1  18.153
Wa       1   0.004
Wb       1   0.288
Wd       1   0.121
LC       1  20.348

Unusual Observations
Obs     Du  Median     Fit  SE Fit  Residual  St Resid
  3   1.00  10.000  10.056   1.021    -0.056     -0.81 X
  4  -1.00   3.000   2.954   1.022     0.046      0.81 X
  5  -0.31   4.000   4.098   1.019    -0.098     -1.09 X
```

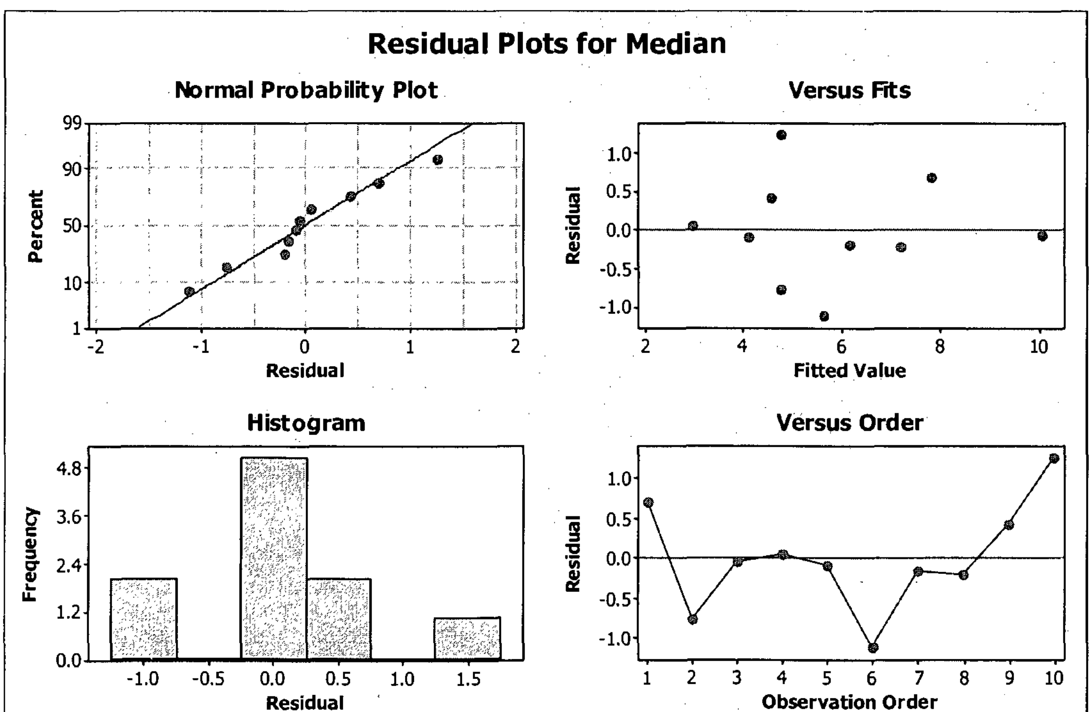
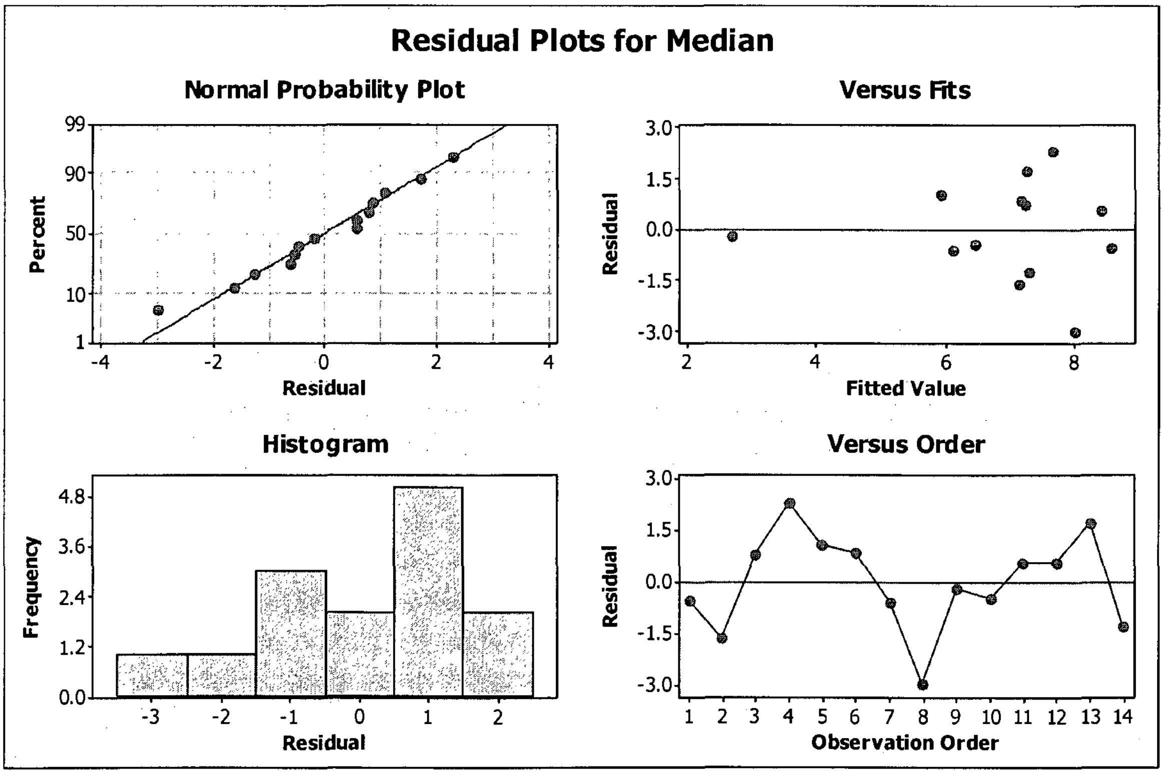


Figure H.3 : Regression analysis: Median versus coded factors (Du, Wa, Wc, Wd, WL) Blue paint panel.

```
The regression equation is
Median = 1.62 - 5.86 du + 7.60 Wa - 47.0 Wc + 49.3 Wd - 17.4 WL

Predictor      Coef  SE Coef      T      P
Constant      1.619    1.960   0.83  0.433
du           -5.858    3.055  -1.92  0.091
Wa            7.601    3.738   2.03  0.076
Wc           -47.04    18.68  -2.52  0.036
Wd            49.34    19.78   2.49  0.037
WL          -17.443    7.563  -2.31  0.050

S = 1.79575   R-Sq = 52.9%   R-Sq(adj) = 23.4%
PRESS = 81.8195   R-Sq(pred) = 0.00%

Analysis of Variance
Source          DF      SS     MS     F      P
Regression       5  28.934  5.787  1.79  0.220
Residual Error   8  25.798  3.225
Total           13  54.732

No replicates. Cannot do pure error test.

Source  DF  Seq SS
du       1   0.031
Wa       1   6.477
Wc       1   2.220
Wd       1   3.054
WL       1  17.153

No evidence of lack of fit (P >= 0.1).
```

Residual Plots for Median



Appendix I: Copyrights releases

From:Sherry.Brown@altana.com
To: geetha.shree@gmail.com
date: Fri, Nov 14, 2008 at 4:46 PM
subject FW: Requesting copyright permission
mailed-by altana.com

Hello,

Yes, you may have permission to use the materials. Please just make sure BYK-Gardner is given credit.

BYK-Gardner USA
9104 Guilford Road
Columbia, MD 21046
and
BYK-Gardner GmbH
Lausitzer Strasse 8
82538 Geretsried
Germany

I included two application notes with some extra information although most of the info is already on our website.

If possible, please send a copy of the completed report.

Feel free to contact me with any other needs.

Thank you considering BYK-Gardner!

Best regards,

Sherry Brown

Marketing Manager

BYK-Gardner USA

A member of Altana

Visit us online at www.byk.com/instruments

Vita Auctoris

Name:	**Geethashree Hemashankar**
Place of Birth:	**Mysore, Karnataka, India**
Education:	**St. Josephs High School, Mysore, India** **Secondary School Certificate (Science)**
	M.M.K. & S.D.M. Mahila Maha Vidyalaya, Mysore, India **Pre-University Certificate (Science)**
	Visveswaraiah Technological University (SJCE), Karnataka, India **B.E. (Environmental Engineering), 2000- 2004**
	University of Windsor, Windsor, Ontario **M.A.Sc (Environmental Engineering),2006-2008.**